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THESIS

LIFT AND DRAG MEASUREMENT AND ANALYSIS
OF THE STERN SEAL OF THE
CAPTURED AIR BUBBLE TESTCRAFT XR-3

by

James Armand Boland

March 1977

Thesis Advisor: D. M. Layton

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REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Lift and Drag Measurement and Analysis of the Stern Seal of the Captured Air Bubble Testcraft XR-3	5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; March 1977 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James Armand Boland	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940	12. REPORT DATE March 1977 13. NUMBER OF PAGES 116
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Postgraduate School Monterey, California 93940	15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Surface Effects Ship
Captured Air Bubble
XR-3

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Lift and Drag Measurement and Analysis of the Stern Seal of the Captured Air Bubble Testcraft XR-3

by

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Lieutenant, United States Navy
B.S., United States Naval Academy, 1969

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

March 1977

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ABSTRACT

Tests were run to measure the total lift and drag forces acting on the stern seal of the surface effect ship testcraft XR-3. Stern seal lift and drag as well as total testcraft drag were plotted against testcraft speed as a function of craft weight, speed, center of gravity and rear seal overpressure.

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I. INTRODUCTION

A. BACKGROUND

Over the past two decades, the United States Navy has recognized the need for advanced concept, high speed, marine vehicles to meet its national defense role. To this end, a program was developed to monitor and test surface effect ships as one possible platform capable of fulfilling the Navy's needs. This program, under the guidance of the Surface Effect Ship Project Office (SESPO), has brought forth several surface effect ships from small one-ton models to two one-hundred-ton models, Refs. 1 and 2. One of these craft, the three-ton surface effect ship XR-3, has been operated by the Naval Postgraduate School since March, 1970.

The XR-3 was constructed in 1965 by the David Taylor Model Basin and subsequently underwent an evaluation by the Navy until October, 1967. The XR-3 was then shipped to the Aerojet-General Corporation for further testing and evaluation under the instructions of the Surface Effect Ship Project Office. The Aerojet-General Corporation conducted one hundred eight hours of water-borne testing in San Diego bay between April and November, 1968.

The XR-3 was transferred to the Naval Postgraduate School (NPS) in March, 1970, for the purpose of investigating several areas of interest in the field of basic and advanced surface effect ship technology in accordance with a SESPO Statement of Work.

While at the Naval Postgraduate School the XR-3 has been used extensively for student research for Master's Degree theses. The test site for the XR-3 is San Antonio Lake located approximately 100 miles south of Monterey.

B. THE XR-3

The XR-3 testcraft, figures 1 and 2, is twenty-four feet long, twelve-feet wide, and weighs 5685 pounds. It is powered by two fifty-five horsepower Chrysler outboard engines, with five single-cylinder air cooled internal combustion engines to provide air to the plenum and seals through single stage axial fans. Electrical power is provided by a 1500 watt, 110 volt auxiliary power unit (APU). The testcraft is designed so that it may be controlled by one pilot.

C. SURFACE EFFECT SHIPS

Surface Effect Ships belong to the family of air cushion vehicles (ACV). Air cushion vehicles are divided into two main groups, hovercraft and captured air bubble. The hovercraft is lifted completely from the water by the aerostatic force of the plenum pressure and therefore constantly vents air from the plenum under the seal. The captured air bubble vessel is lifted only partially from the water and does not normally vent air from the plenum. With this in mind, it can be seen that the hovercraft can operate over land as well as water since it does not actually touch the surface over which it travels. It should be apparent

that the hovercraft also requires a large plenum pressure to lift it clear of the surface and therefore large lift engines.

The captured air bubble craft, pictured in figure 3, consists of two rigid sidewalls with seals fore and aft to contain the air bubble. Since the sidewalls and seals always extend into the water, the surface effect ship or captured air bubble craft never operates out of the water. The advantage of these craft over hovercraft is that less power is required for lifting the craft since approximately twenty percent of the craft's weight is supported by hydrostatic forces. In large surface effect ships, the sidewalls provide access to sea water for propulsion and ships cooling systems.

Figure 4 shows a typical drag versus speed curve for the XR-3. As the craft accelerates from rest, it will begin to push two waves, one at the bow and one at the stern. Point 1, which is called Secondary Hump, is the speed at which the craft rides over the stern wave with a subsequent reduction of drag. Figure 5 shows the XR-3 at a speed just below point 1. Air can be seen venting under the sidewall in the space created by the bow and stern waves. The craft can rarely operate between points 1 and 2 because the slope of the drag curve is negative. With a negative slope, only unstable equilibrium can be achieved in this speed range. From point 2 to point 3, drag again increases until the craft overrides its bow wave at point 3. Figure 6 shows the XR-3 operating at a speed between the secondary and primary humps (points 1 and 3 of figure 4). It can be seen that the testcraft has only a bow wave in this speed range. At speeds above point 3, the craft is said to be "on the cushion". The process of going from rest past point 3 is called "transitioning" or "going over the Hump". Figures 7 and 8 show the XR-3 "on the cushion". It can be seen in the

photographs that there is neither a bow nor stern wave in this speed range.

D. THESIS OBJECTIVE

In order to improve the design of future surface effect ships, it is necessary to investigate all the sources of drag acting on the craft. Each force may then be reduced to its lowest possible value to attain the maximum craft speed for a given power plant. To this end, many investigations have been done on the XR-3. Reference 3 details the investigation of total craft drag as a function of speed. Reference 4 found the aerostatic forces acting on the rear seal. This report deals with the determination of the total force acting on the rear seal and its two components, aerostatic and hydrodynamic forces.

II. NATURE OF THE PROBLEM

The lift and drag exerted on the rear seal of a surface effect ship come from two sources, aerostatic pressure and hydrodynamic action. The aerostatic force comes from the plenum pressure acting on the forward face of the seal. Measurement of this force would be a simple matter if the plenum pressure was constant over the entire face of the seal. This is, unfortunately, not the case as air is constantly being pumped into the plenum from the lift fans and is at the same time venting from the plenum either under the seals or under the sidewalls during transition. The air pressure in the plenum exerts a force on each sidewall and on the bow and stern seals. Due to symmetry, the forces on the sidewalls are equal and opposite. Although this must be accounted for in the hull strength calculations during surface effect ship design, it does not affect craft dynamic performance.

The forces on the two seals are not equal due to several effects. First, both seals are raked aft from top to bottom causing the plenum pressure to force the bow seal down into the water and lift the stern seal out of the water. Secondly, the bow seal has a relatively constant pressure on its inside face since two lift fans provide air directly to the bow seal which in turn vents excess air into the plenum. The stern seal experiences a much different situation in that some air vents under the seal during almost all operating conditions. Figure 9 shows a typical pressure distribution on the forward face of the rear seal. For

further information on the pressure distribution on the forward face of the rear seal, see Ref. 4; and for the pressure distribution inside the plenum, see Refs. 5 and 6.

It can be seen from figure 9 that the plenum pressure pushes the rear seal up and aft over most of the seal's surface. It should also be observed that the air venting under the seal passes through a venturi created by the bottom of the seal and the water over which the craft is passing. Since the air pressure in the plenum acting on the rear seal is variable both vertically and athwartships, even to the point of being negative, and the rear seal is pushed upwards reducing the seal area, the aft force on the rear seal is less than the forward force on the bow seal. This difference in static pressure results in an aerostatic force which pushes the craft forward. Figure 10 shows the XR-3 venting under the stern seal while the craft speed is near zero.

Measurement of the aerostatic lift and drag forces on the rear seal is further complicated by the seal's lack of rigidity. The seal face is made from rubberized fabric reinforced with spring metal bands. This type of fabrication allows the seal to distort from wave action and also from the pressure distribution on the seal face. The ability of the seal to distort is desirable from the point of view of craft motion since wave energy will be absorbed by the seal rather than creating a lifting force to increase craft heave.

To find the hydrodynamic forces on the rear seal it is necessary to measure the total lift and drag forces on the seal and then subtract the aerostatic force. Reference 4 details the procedure for measuring the aerostatic forces. This procedure basically consists of measuring the air pressure at discrete points along the face of the seal and

resolving the pressure into lift and drag forces based on the shape of the seal at the time of measurement. The seal shape was obtained by photographing the seal against a grid painted on the inside of the sidewall, figure 11. The picture was made with a polaroid camera and a low-light television camera mounted inside the plenum.

III. DESCRIPTION OF EQUIPMENT AND PROCEDURES

A. THE REAR SEAL

The rear seal of the XR-3 consists of a rectangular frame 120 inches by 46 inches constructed of two-inch angle aluminum stock welded at the corners. The seal is reinforced in the fore and aft direction by three-inch aluminum channel stock. The seal bag is a rubberized fabric riveted and glued to the aluminum frame. The face of the seal has 12 equally spaced 4 x 48 inch steel springs to give it shape and an element of rigidity.

The seal bag consists of two compartments separated by a center membrane. The center membrane has several large holes to allow air to flow freely between the two sections of the seal. The holes in the center membrane also allow any water that enters the seal to move to the lowest point in the seal where it is blown out through small holes at the rear of the seal. Figure 12 shows the port half of the rear seal which is identical to the bow seal. Figure 13 shows a side view of the rear seal including the control cables. The control cables were used during earlier experiments, Ref. 7, to determine an optimum seal shape. For all but one set of runs during this investigation, the cables were stopped off at point A corresponding to the optimum shape and then disconnected from the winches. For the one remaining set of runs the seal shape was changed in an attempt to reduce the seal to water contact area. Removing the cables from the winches was necessary to prevent the

cables from putting a load on the seal that would not be measured by this experiment.

In order to measure the total lift and drag it was necessary to suspend the rear seal by load cells capable of measuring the lift and drag forces on the seal. This required the following modifications to the seal.

As originally designed, the seal only had frame stiffeners in the fore and aft direction since the seal was bolted directly to the wet deck. In order to suspend the seal, it was necessary to stiffen the seal athwartships to keep the seal from drooping at the ends. To allow the seal to fit back into the testcraft without extensive modification, it was necessary to put the stiffeners below the existing three-inch channels in the seal. Continuous one-inch channel stock from one side of the seal to the other would have been preferable; however, this could not be accomplished without cutting holes in the seal fabric to get the one-inch channels under the three-inch channels. The solution was to use three 48-inch long sections of channel stock which were short enough to fit into the seal from the top and then bolt the sections together to form a continuous length. Two stiffeners were used, spaced approximately one-third and two-thirds the distance from the front of the seal frame to the rear of the seal frame. Figure 14 shows the top of the rear seal after the seal had the stiffeners installed.

Figure 15 shows the load cell to seal attachment points. These were made by first drilling holes in the one-inch stiffeners and inserting 1/2" x 13 threads per inch (TPI) bolts through 1/4-inch bearing plates and then through the hole in the stiffener. Connectors were fabricated from one-inch hexagonal stock which was cut to two-inch lengths, drilled down the center and threaded to 1/2" x 13 TPI.

Figure 16 shows the top of the seal at this point in the assembly.

To measure the lift forces on the seal it was necessary to keep the top of the seal at ambient pressure rather than at plenum pressure; therefore, the front edge of the seal required a method of blocking plenum air from escaping over the top of the seal. This was accomplished by gluing a plastic sheet to the leading edge of the seal frame and then attaching the sheet to the wet deck with glue and heavy tape. Figure 17 shows the plastic sheet being installed on the leading edge of the seal.

Originally, the seal was bolted directly to the XR-3's wet deck, allowing the wet deck to serve as the upper boundary of the seal's air cavity. Aluminum sheet metal, .025 inch thick, was used to seal the top of the stern seal by riveting it directly to the top of the angle aluminum frame using a caulking compound as a sealer. The plastic sheet previously mentioned was fit between the angle aluminum frame and the sheet metal prior to assembly. The aluminum sheet had an eight-inch hole cut into which a two-inch collar was placed. This hole allowed air from lift fan number one to flow into the seal and pressurize it. The joint between the collar and the sheet metal and the joint between the sheet metal and the seal frame were caulked to make the seal as air tight as possible. Figure 18 shows the air hole in the sheet metal top of the seal.

The drag cells were attached to the front of the seal by bolting a bracket to the leading edge of the seal which allows a threaded rod to be attached. Figure 19 shows the completed seal with lift and drag load cells attached and includes the numbering system.

To attach the lift cells to the boat, 1/2-inch aluminum plates were attached to exsisting hull strength members in the stern athwartships plenum. The load cells had 1/2" x 13 TPI threaded rods attached to each end, one end of which was screwed into the previously described attachment points on the seal, and the other end was attached to the 1/2-inch aluminum plate by inserting it through a hole in the plate with washers and nuts, both top and bottom. Figure 20 shows a lift load cell as seen from the weather deck with the access plate removed.

The drag load cells were secured by attaching a 1/2-inch aluminum plate to the wet deck; the bolts extended through another 1/2-inch plate above the stringers in the wet deck. An aluminum bracket was attached to the flat plate at an angle of 90 degrees. The drag load cells were connected between this vertical bracket and the bracket on the leading edge of the seal by 1/2" x 13 TPI threaded rods. Figure 21 shows one of the two drag load cells installed with the two mounting brackets.

B. LIFT AND DRAG LOAD CELL ELECTRONICS

The lift and drag load cells receive power from and send signals to an electronics package designed for this project. Figure 22 shows the load cell circuit. Power is received from the craft's 12 volt system and reduced to five volts by a 7805 LM340K electronic voltage regulator. The plus five volts and ground feed directly to the load cell at opposite ends of the bridge. The five volt output of the regulator is also reduced by a 20,000-ohm resistor and connected to the center tap of the load cell as a zero adjustment. A calibration resistor is provided on one leg of the load cell

to aid in adjusting the amplifier gain. The signal from the load cell passes through the "ON-ZERO" switch which will either pass the signal (ON) or short the amplifier input to ground (ZERO) to set the amplifier zero. The main signal is amplified by a pair of 741 operational amplifiers (op amp) in series. Circuit gain is adjusted by a 20,000-ohm resistor in the feedback loop of the second 741 operational amplifier. The circuits are designed so that a plus signal from this circuit is an upward lift force or a rearward drag force.

The output of the load cell circuit goes either to the lift summation circuit, figure 23, or the drag summation circuit, figure 24. Lift summation is done by a 3440J summer. Individual signal gains are adjusted by the four 51,000-ohm resistors. The summer is followed by a 741 operational amplifier to provide signal inversion so that the output signal is of the same sign as the input signal (positive-upward; negative-downward). Drag summation is accomplished by a 3440J summer as in the lift circuit; however, the drag summation circuit does not reinvert the output signal. The drag summation circuit output is therefore negative for a rearward force and positive for a forward force.

C. SEAL POSITION MEASUREMENT SYSTEM

To determine the shape of the rear seal it was necessary to measure the position of the seal's trailing edge. Figures 25 and 26 show the method used during this investigation which consisted of five nylon lines attached to the trailing edge of the seal. These lines were routed over a horizontal bar attached to the transom and then through eye hooks up the port side of the testcraft.

Finally the lines were hooked to heavy elastics to avoid slack. Reference marks were made on each line corresponding to a known displacement of the seal edge below the wet deck. A graduated scale was laid out on the deck against which the reference marks could be compared.

This method only yielded qualitative results since the strings were routed around the rear seal which was not rigid. Being flexible, the string arc length varied according to the pressure in the seal. However, this method provided data that was sufficiently accurate to get comparative information. The results of these measurements will be included in a separate report.

D. DATA ACQUISITION AND REDUCTION SYSTEM

At the beginning of this project, the XR-3 had a data acquisition system which consisted of various transducers feeding to amplifiers and/or signal conditioners and then to a 14 channel tape recorder. The data acquisition system is shown in figure 21.

1. Sensors

The installed sensors measure:

1. Port thrust *
2. Starboard thrust *
3. Bow seal pressure
4. Stern seal pressure *

* These parameters were used in this investigation.

5. Plenum pressure *
6. Testcraft velocity *
7. Wave height
8. Pitch angle *
9. Pitch rate
10. Roll angle
11. Roll rate
12. Yaw angle
13. Yaw rate
14. Lateral acceleration
15. Longitudinal acceleration
16. Vertical acceleration
17. Rudder position

* These parameters were used in this investigation.

The thrust measurement system consists of two Revere USPI-150A balanced bridge transducers. Each engine mount is constrained vertically and athwartships by mounting structure but must pass all forward thrust through the transducer. This mounting, therefore, permits the transducer to pick up only the component of thrust that drives the boat directly ahead. The output of the balanced bridge transducer is fed to one of ten Grant Model DCAB-3 amplifiers. The Grant amplifiers boost the signal to a range of 0.0 to 1.0 volts to correspond to 0.0 to 500.0 pounds of thrust. External circuitry provides calibration signals of 0.0, 0.5 and 1.0 volts.

Bow seal, stern seal, and plenum pressures are measured by Varian differential pressure transducers which are connected to their sensing points by flexible hoses. The pressure transducer signals also go to Grant amplifiers with an output of 0.0 to 1.0 volt representing 0.0 to 60.0 pounds per square foot (PSF).

Testcraft velocity is measured by a Potter velocity meter which consists of a small magnetized free turbine mounted in a probe. The probe is held in the undisturbed water ahead of the testcraft by a support structure mounted on the bow. The support structure is shown in figures 1 and 2. The velocity conditioning unit converts the frequency output of the velocity probe to two outputs, 0.0 to 5.0 volts for the cockpit instrumentation and 0.0 to 1.0 volt to be fed into the tape recorder. These voltages correspond to a velocity range of zero to 40 knots.

Wave height is measured by a Western Marine Electronics Model LM4001A ultrasonic height sensor. The sensor for this unit is mounted on the same structure as the velocity probe. The output of the height sensor is fed to the height sensor conditioner which has an output of 0.0 to 1.0 volt corresponding to -2 to +2 feet.

The Humphreys Model CF18-0101-1 gyro package provides angles and rates of pitch, roll and yaw. Outputs of the Humphreys unit are in the range of 0.0 to 1.0 volt corresponding to -15 to +15 degrees of pitch, -20 to +20 degrees of roll, -180 to +180 degrees yaw, and ±30 degrees per second for all rates.

2. Data Recorder

The outputs of the amplifier and conditioning units are connected via terminal strips to the onboard tape recorder. The terminal strips allow the test coordinator to select the sensors to be recorded for the day's runs and to arrange them on the tape in the optimum manner. The tape recorder is a Pemco Model 120-B, 14 channel magnetic reel-to-reel recorder. The tape recorder has an edge track which is used to voice record events as they happen. The recorder is controllable either from the front of the recorder or remotely from the pilot's cockpit. Weighing only 100 pounds, the tape recorder may easily be moved from the testcraft to the data reduction site.

The recorder can be operated at various speeds from 1 7/8 to 60 inches per minute using 1.0 or 1.5 mil, one-inch tape.

3. Data Reduction System

The data reduction system, figure 28, consists of a signal conditioning unit, a two channel strip chart recorder, analog to digital converter, programable calculator with storage, and a digital X-Y recorder.

The signal conditioning unit receives all 14 channels from the tape recorder and through use of a patching matrix will provide up to nine output channels through signal conditioning amplifiers. All nine output channels have front pannel controls to adjust zero and gain based on the calibration signals on the tape. The amplifiers have high frequency filters (low pass) to

eliminate high frequency noise. The signal conditioning unit has a digital voltmeter using a rotary switch which allows monitoring any of the 14 input or nine output channels. The conditioning unit has a summing and halfing module which is normally used to sum the two thrust signals. The summer output will be 0.0 to 5.0 volts representing zero to 1000 pounds of thrust while each input is 0.0 to 5.0 volts representing zero to 500 pounds of thrust.

Also mounted in the signal conditioning unit is the analog to digital converter and calculator interface module. The digital output is connected to a Monroe 1880 calculator which through a stored program will output two selected signal values at the time of request and send the information to a Monroe PL-4 digital X-Y plotter where it is automatically plotted. The analog signal is either measured by a digital multimeter or recorded by the Hewlett-Packard Model 7100-B strip chart recorder. Additional information about the data reduction system may be found in Ref. 6.

IV. EXPERIMENTAL PROCEDURE

At the beginning of each day's runs, the voice edge track of the tape was annotated with the necessary information. Calibration procedures were developed for the newly installed equipment and added to existing procedures for the original equipment. The calibration signals provided by the lift and drag circuitry were zeros and 200 millivolts (200 pounds) on all circuits.

Experimental runs were made with the testcraft to determine the effects of craft weight, center of gravity, rear seal inflation pressure and shape. The base condition was established with a craft weight of 6090 pounds at a center of gravity of 117.3 inches, measured forward from the transom. This test condition represents the craft loaded with a pilot and test coordinator both sitting in the cockpits. Runs were made at this weight with the rear seal by-pass fully open. Holding the weight and by-pass conditions constant, the center of gravity was moved forward to 119.6 inches and then aft to 113.5 inches. The testcraft was loaded to 6810 pounds and run at the three centers of gravity. The testcraft was again brought back to its original weight of 6090 pounds and run at the three centers of gravity with the stern seal by-pass 92 percent closed. Based on the results of the above runs, the rear seal shape was altered to reduce the seal to water contact area and the rear seal by-pass was closed fully.

To obtain data points over the entire range of testcraft speeds, runs were conducted starting at the lowest power setting and holding it for one minute or more. A small

increment of power was added and again held for at least one minute. This procedure was necessary in the sub-hump region because testcraft speed changes very little for a given amount of power. This procedure also provided sufficient data points to define clearly the secondary hump on all plots. After the testcraft transitioned at about 6.5 knots, the speed would climb rapidly until equilibrium was reached at a point on the total drag curve where there was a positive slope. Power was then reduced to "back into the hump" at point 2 of figure 4. Again power was applied in small increments until the testcraft passed the primary hump at about ten knots. From this point to full power the testcraft was brought to specific speeds, usually two knots apart, which was sufficient to define the curve on all plots. It was occasionally necessary to repeat certain conditions if the data appeared to deviate from expected values when uncontrollable conditions such as bad weather or boat wakes on the lake were known to be present.

Data reduction was done by obtaining stripchart traces of the day's runs and reading the values by hand with mental averaging of signal noise. This method proved satisfactory since runs made for the same condition, i.e. same weight, center of gravity and by-pass condition, taken on different days yielded repeatable data. All data was hand plotted giving more weight to data taken on days of good weather conditions.

V. RESULTS AND CONCLUSIONS

The data obtained during this investigation is presented in tabular form in Appendix A and in graphical form in Appendix B. Figures 30 through 32 are summary plots which will be used to show the effects of changes in the problem variables on the shape of the curves. The data will be examined from two aspects; first, the shape of the curves as they relate to what is physically happening to the testcraft and wave pattern, and secondly how the problem variables affect the shape and displacement of each curve.

General lift and drag curves for the XR-3 rear seal are presented in figure 29. It is well to point out at this time that the lift and drag forces measured on the rear seal are primarily due to the plenum air pressure acting on the horizontal and vertical projected areas of the seal face and that anything that affects either the projected area of the seal face or the plenum pressure will change the lift and drag forces. The profile of the rear seal is shown in figure 13 for the seal hanging free. The seal shape is altered when the testcraft is waterborne in that the forward section of the seal retains approximately the same profile as the free hanging seal, but the rear one-third to one-half becomes much flatter as it skims across the surface of the water. Since air is flowing under the seal, the air pressure must be decreasing from that of the plenum to that of the atmosphere; the flattened area of the seal will be exposed to less of a lifting force than that part of the seal exposed to full plenum pressure. The measured lift on the seal is therefore inversely proportional to the seal to water contact area. The drag force on the seal should be

directly proportional to the distance the seal extends below the wet deck of the testcraft since this is what determines the horizontal projected area of the seal.

Referring to figure 29, as the testcraft increases speed from point 1 to point 2, both lift and drag increase. While in this speed range, the testcraft is creating a bow and stern wave with the stern wave located almost amidships. The stern seal begins to expand into the trough behind the stern wave and in doing so increases both its horizontal and vertical projected areas which increases both lift and drag. At point 2, the trough between the bow and stern waves becomes deep enough to allow the plenum to vent under the sidewalls. This venting reduces the plenum pressure and with it the lift and drag forces on the seal. It should be noted that the individual lift and drag curves show a considerable amount of scatter in the data at point 2. This scatter is attributed to two things; First, if the lateral center of gravity is not exactly in the center of the testcraft, the plenum will vent to the side away from the center of gravity. Venting begins at a lower speed since the trough between the bow and stern wave does not have to become as deep for venting to begin. The other cause of scatter in this area is the local weather. The small waves induced by the wind superimpose themselves on the testcraft's wave pattern and in doing so add and subtract from the trough height. This allows the testcraft to vent at times that it would not normally be venting under smooth water conditions.

At point 3 the testcraft transitions by overriding the stern wave. It is assumed that the curves connect directly from point 3 to point 4, but data cannot be obtained in this region because the craft cannot operate at steady state due to the unstable equilibrium mentioned earlier.

At point 4 the lift and drag curves go to opposite extremes, lift to a maximum and drag to a minimum. The seal position indicators show that the seal does not extend very far after the stern wave passes under it; therefore the projected area in the horizontal direction is still small and the drag is small. The lift is maximum at this point, however, because of the wave pattern around the testcraft. The stern wave at this point is less than two feet behind the testcraft with a depression under the craft caused by the plenum pressure. As the depressed water in the plenum rises to the stern wave, the area of contact with the stern seal is confined to a small area at the trailing edge of the seal. With the contact area small, the lift force is high due to the large area exposed to plenum pressure as mentioned earlier.

The slope of the curves approaches zero at point 5 as the wave pattern around the testcraft in this speed range remains constant. The slope of the curves becomes negative around point 6 due to a changing pressure distribution in the plenum, as reported in Ref. 6. As the craft speed increases, the pressure at the aft end of the plenum decreases so that the seal face is exposed to less pressure.

The testcraft total drag curve was discussed in section I, C of this report with the curve shown in figure 4.

The effect of closing the rear seal by-pass is to raise the pressure in the stern seal which deforms the seal by bowing out the center of the seal face which increases the seal to water contact area. With increased contact area the lift is less, the craft becomes slightly pitched up and the stern seal does not extend as far as normal. Since the stern seal is not extended as far as usual, the drag is

reduced. The reduced lift and drag can be seen over the entire speed range of the testcraft.

An increase in craft weight increases the amount of lift and drag over the entire range of speed. One other effect can be seen in the sub-hump region and that is the lack of a sharp peak before venting begins. This is attributed to the stern wave building up sooner due to the increased submergence of the sidewalls and bubble cavity.

Changes in the center of gravity have the most noticeable affect on the shape of the lift and drag curves. A much sharper peak in the lift curve can be seen when the center of gravity is moved forward and practically no peak at all when the center of gravity is moved aft. This is caused by the difference in speed at which venting begins. When the center of gravity is moved forward, the forward ends of the sidewalls are more deeply submerged than when the center of gravity is aft. Since venting begins forward and moves aft along the sidewall, a much larger stern wave and trough must build up before venting can begin when the center of gravity is forward. By the same reasoning, a smaller stern wave is required for venting when the center of gravity is aft yielding a smaller peak and earlier transition.

In the post-hump range, two things may be noted: The center of gravity curves for a given weight and by-pass condition cross, and the magnitude of the lift and drag increases as the center of gravity moves aft. Neither of these observations is surprising since the center of lift must move aft with the center of gravity to keep the craft in equilibrium. The stern seal must provide at least part of this added lift. The lift vs. speed curves must cross since the craft transitions earlier when the center of gravity is aft as noted earlier.

The effects of parameter changes on the craft total drag may be seen in figure 32. The speed at which the craft transitions follows the center of gravity; as the center of gravity moves aft, the craft transitions at a lower speed.

Reference 9 noted that there was an optimum center of gravity where the total craft drag was a minimum. It was noted during this investigation that at higher speeds the minimum craft drag was when the center of gravity was aft. This is attributed to the fact that moving the center of gravity aft increases the craft's nose-up pitch which in turn allows the sidewalls to generate hydrodynamic lift at higher speed. At speeds around the primary hump, the minimum total drag curve is at a different center of gravity for each condition of weight and by-pass closure. This shows that the optimum center of gravity changes with testcraft weight and by-pass closure and to operate the craft most efficiently over the entire speed range, the center of gravity must be moved as the craft speed changes.

Reshaping the rear seal reduced the seal drag while maintaining the seal lift constant. The intent of shaping the seal was to reduce the seal to water contact area by holding up the center section of the seal with the control cables and using a higher pressure in the seal to force the trailing edge of the seal down into the water. It was predicted that the lift and drag on the seal would be maximum and the total craft drag would be minimum in this configuration. These results were not achieved because sufficient air pressure could not be generated to force the trailing edge of the seal down into the water against the force of the seal springs. As a result, the seal would not extend very far from the testcraft keeping the horizontal projected area small and with it the seal drag. The lifting area of the seal was essentially unchanged and therefore little change was seen in the seal lift. The total craft

drag increased since the craft pitched up resulting in the stern sections of the sidewalls being further submerged than normal for the craft loading condition causing an increase in wave drag.

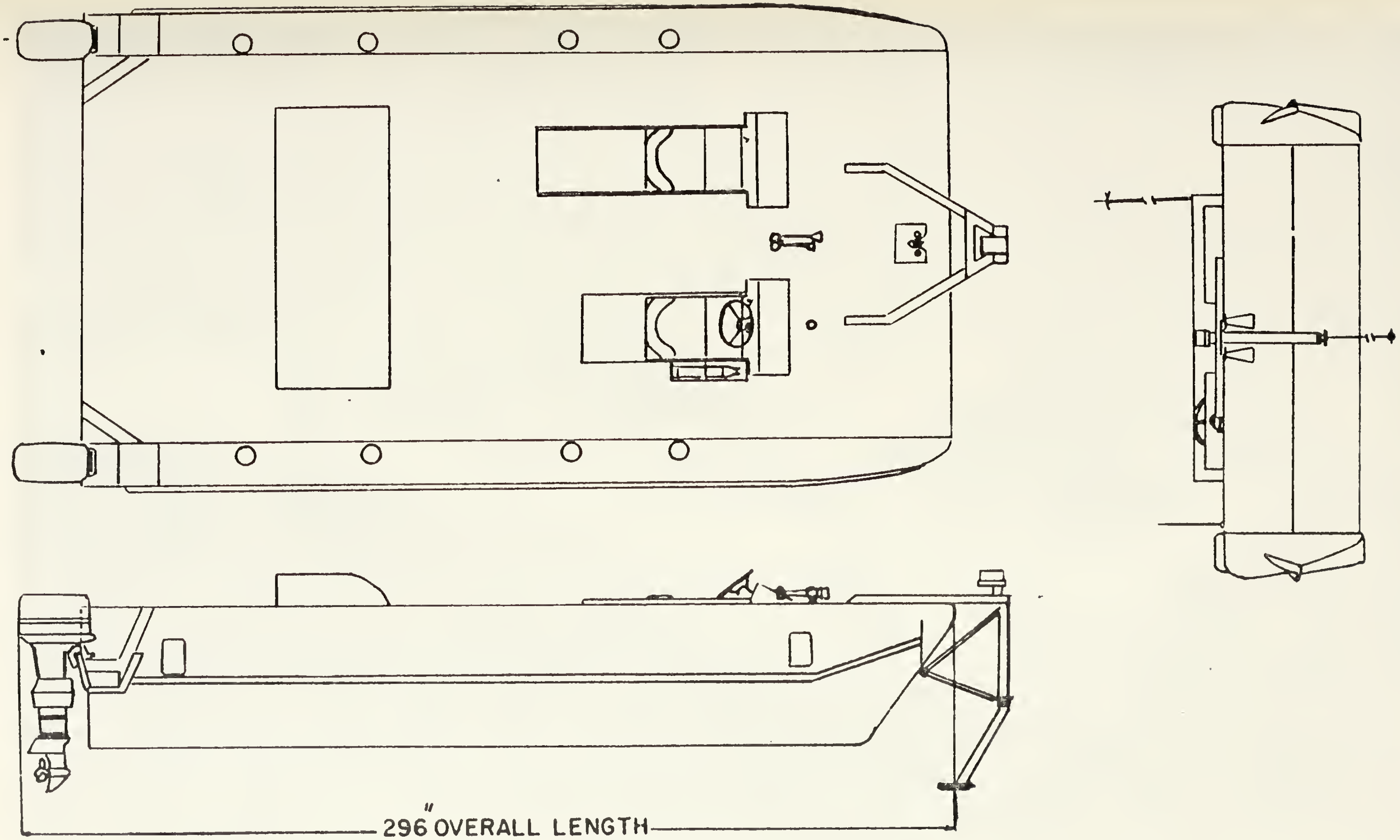

Figure 1 - XR-3 GENERAL CONFIGURATION

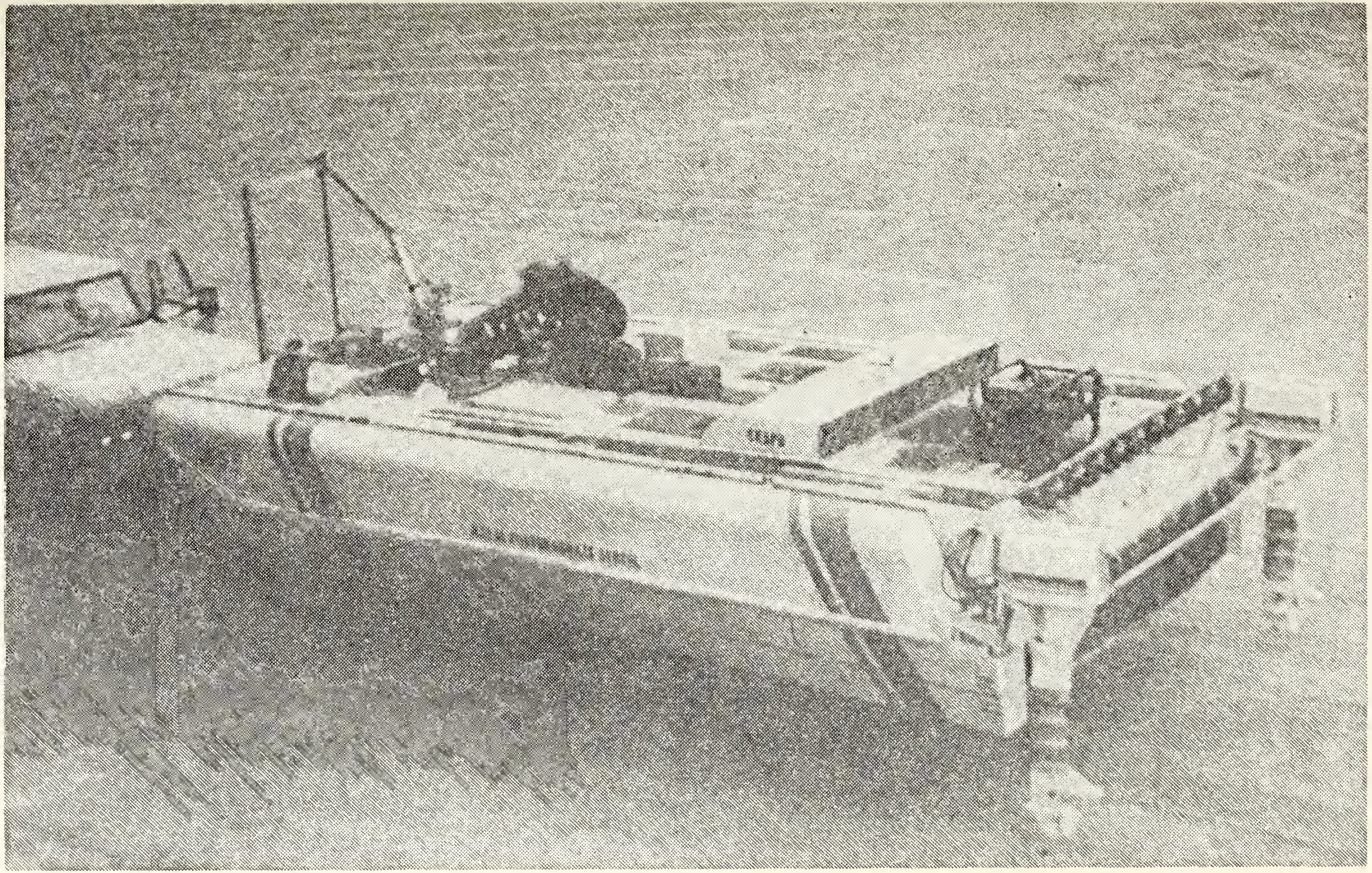

Figure 2 - XR-3 TESTCRAFT - GENERAL APPEARANCE

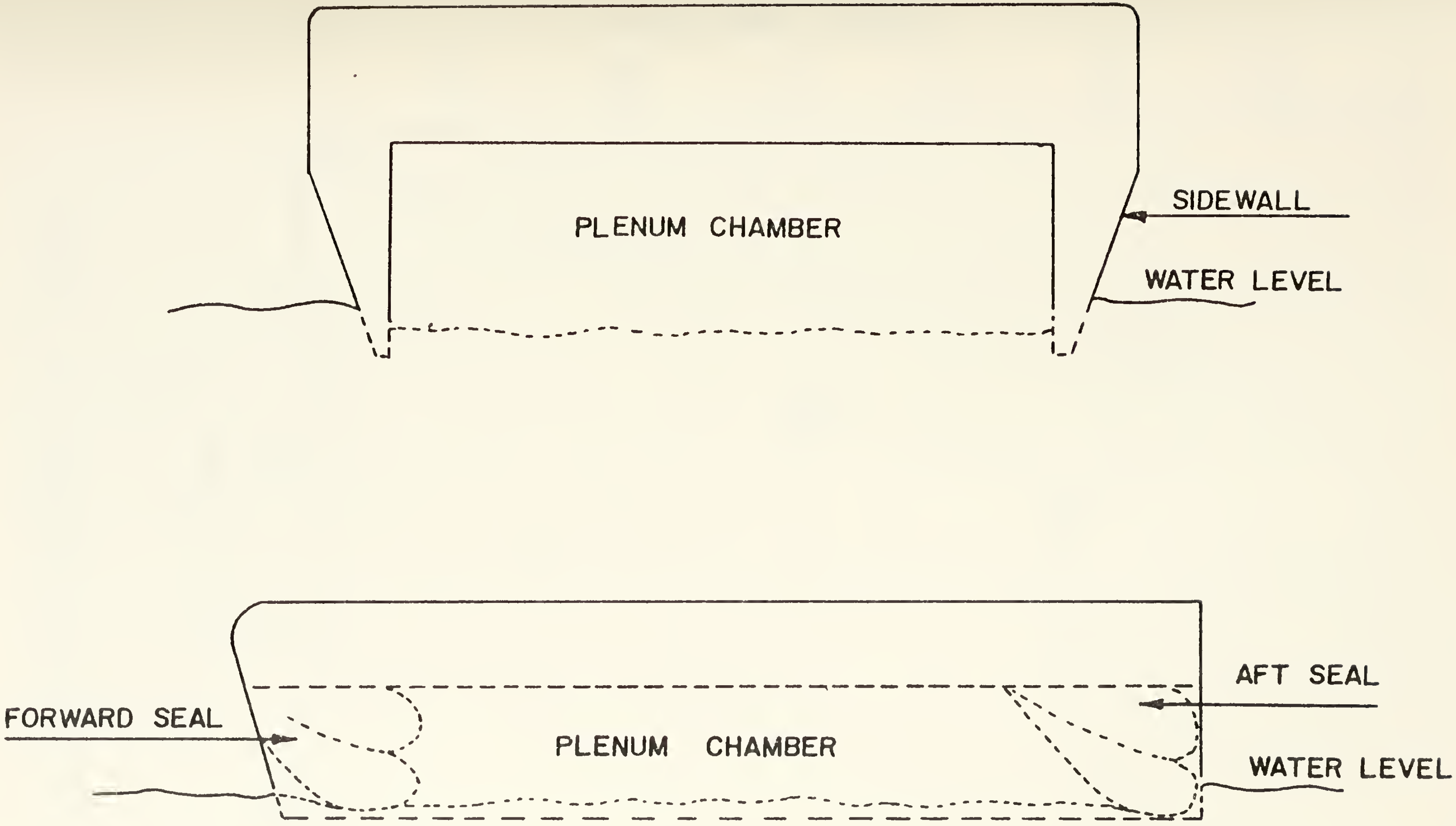

Figure 3 - PLENUM CHAMBER OUTLINE

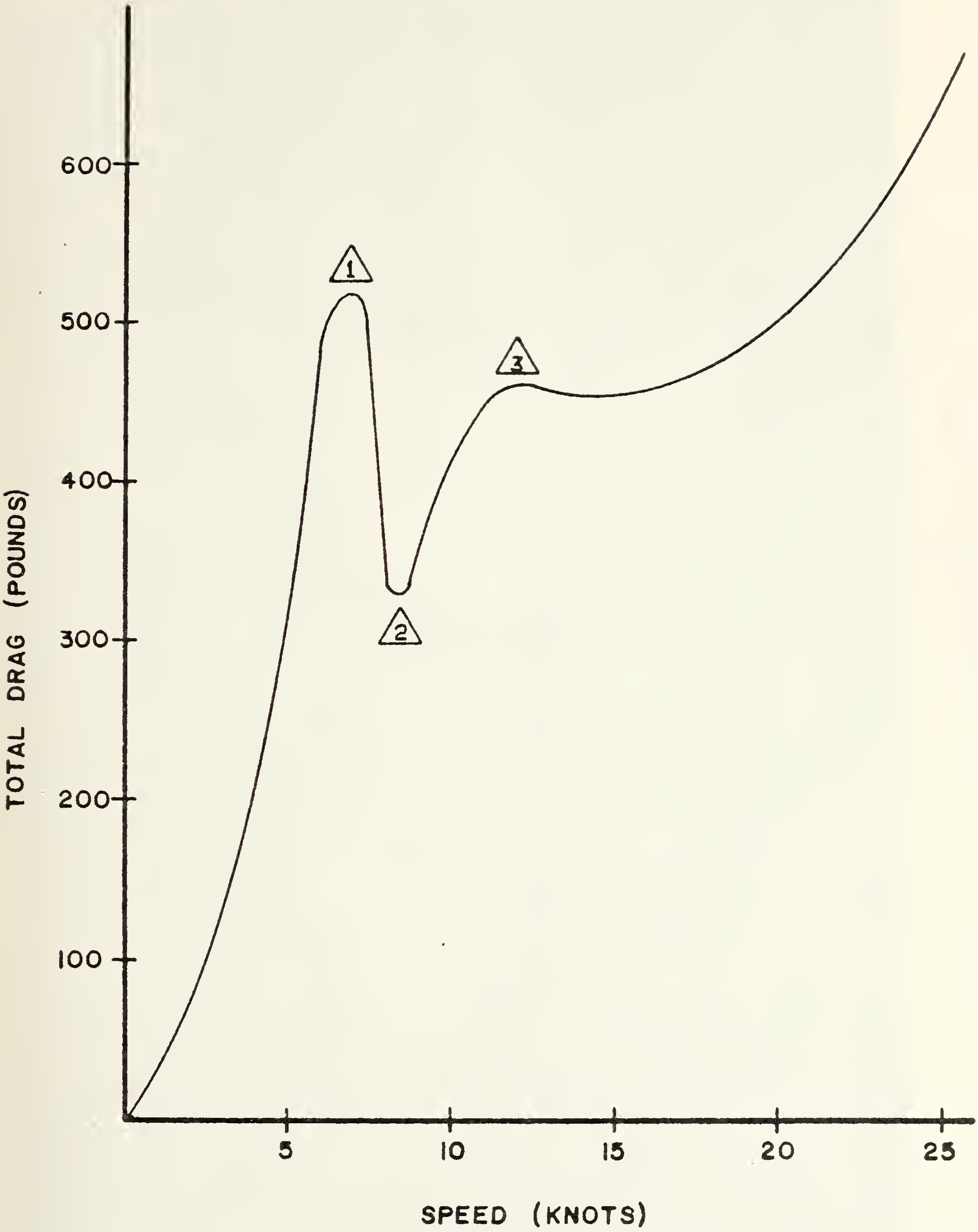

Figure 4 - TESTCRAFT DRAG VERSUS SPEED

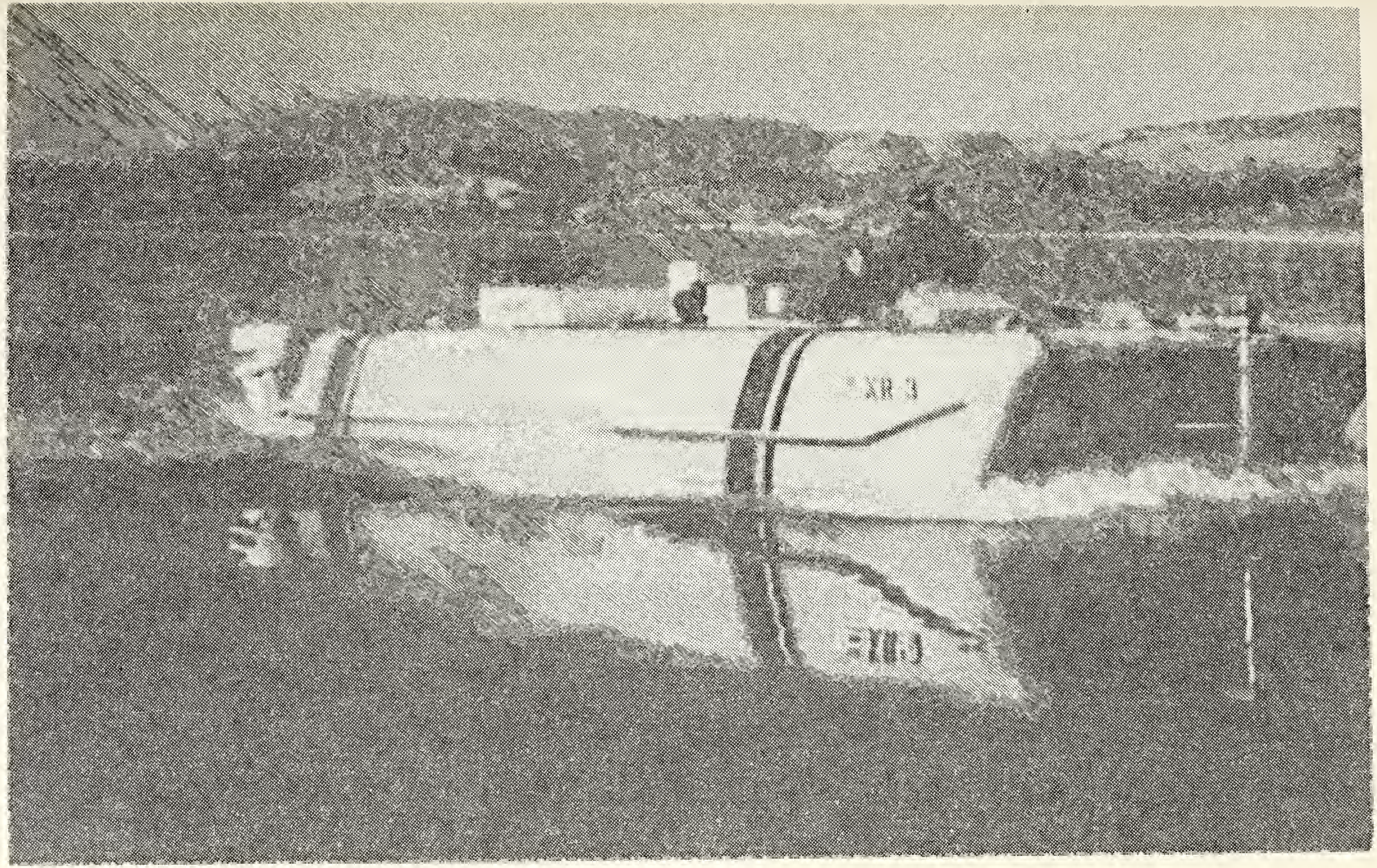

Figure 5 - XR-3 VENTING UNDER SIDEWALL

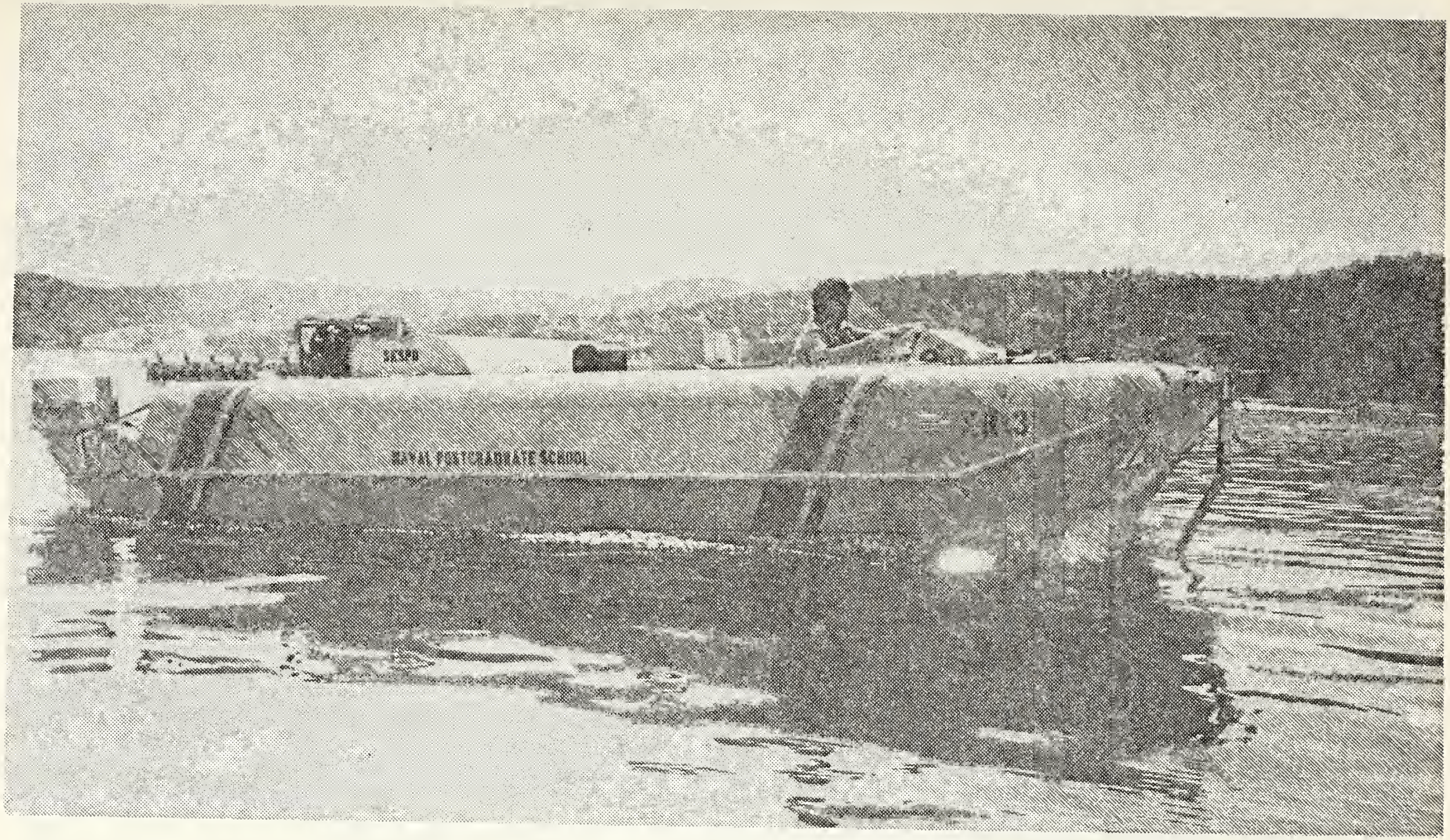

Figure 6 - XR-3 SHOWING ONLY A BOW WAVE

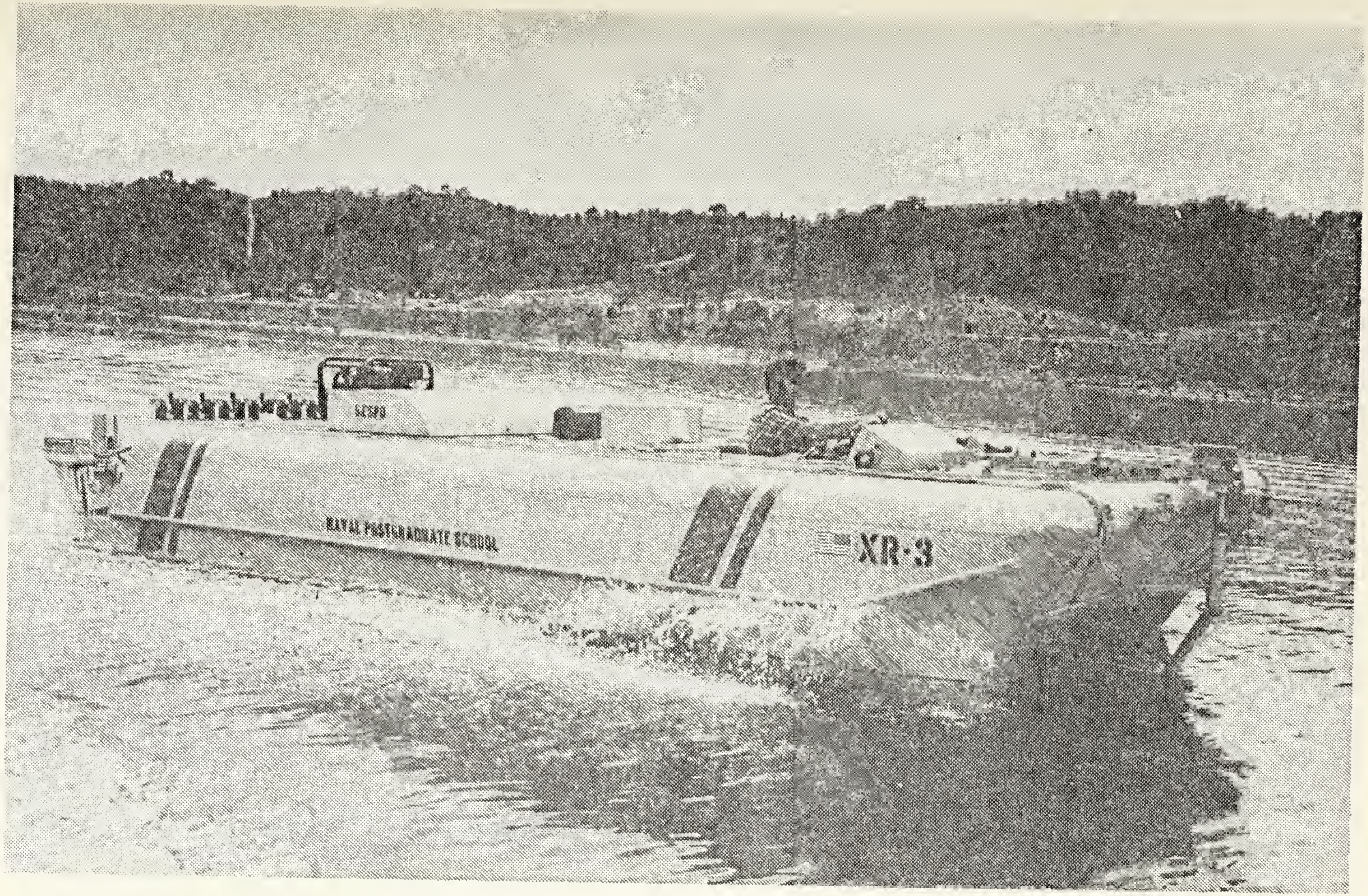

Figure 7 - XR-3 POST HUMP - FRONT VIEW

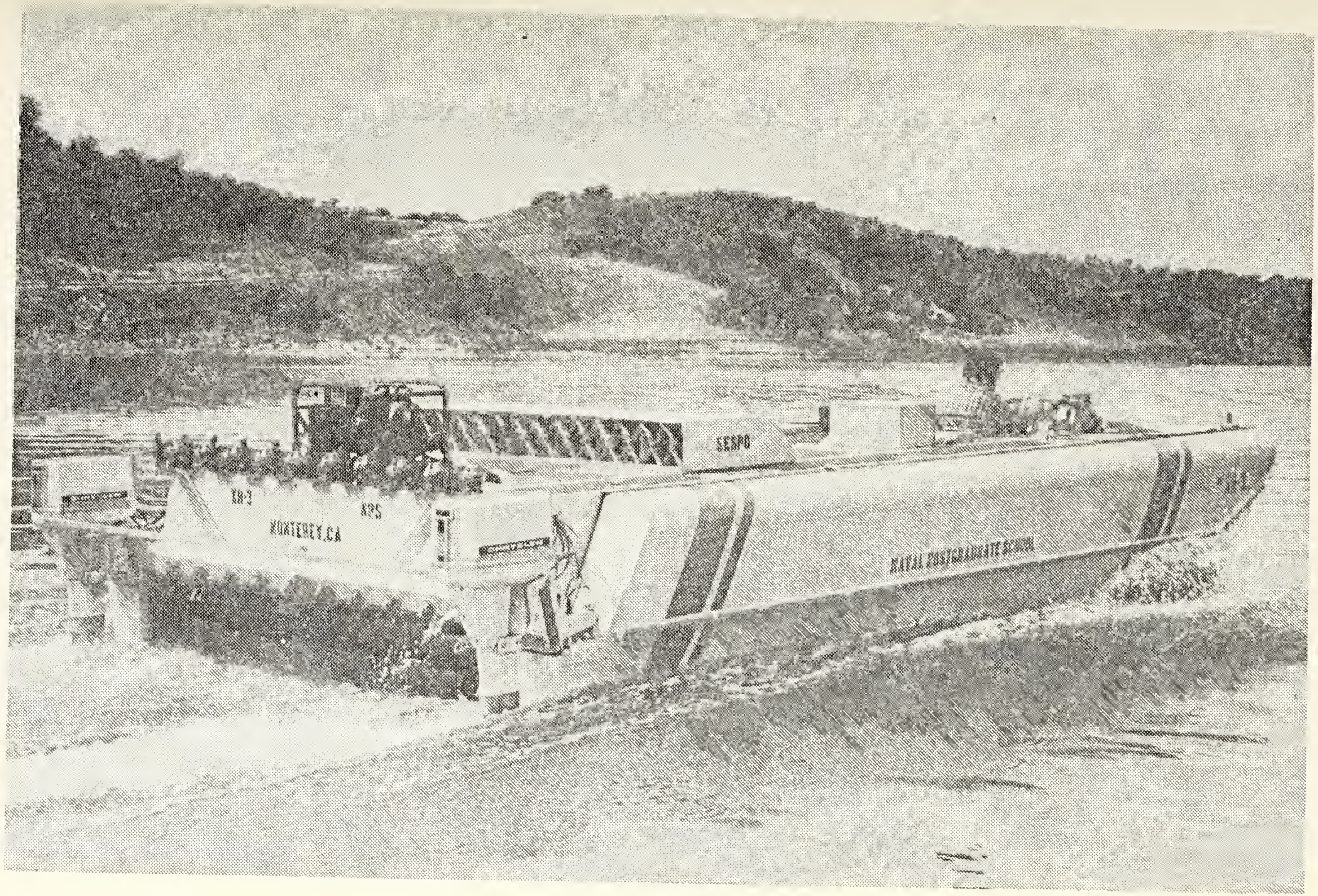

Figure 8 - XR-3 POST HUMP - REAR VIEW

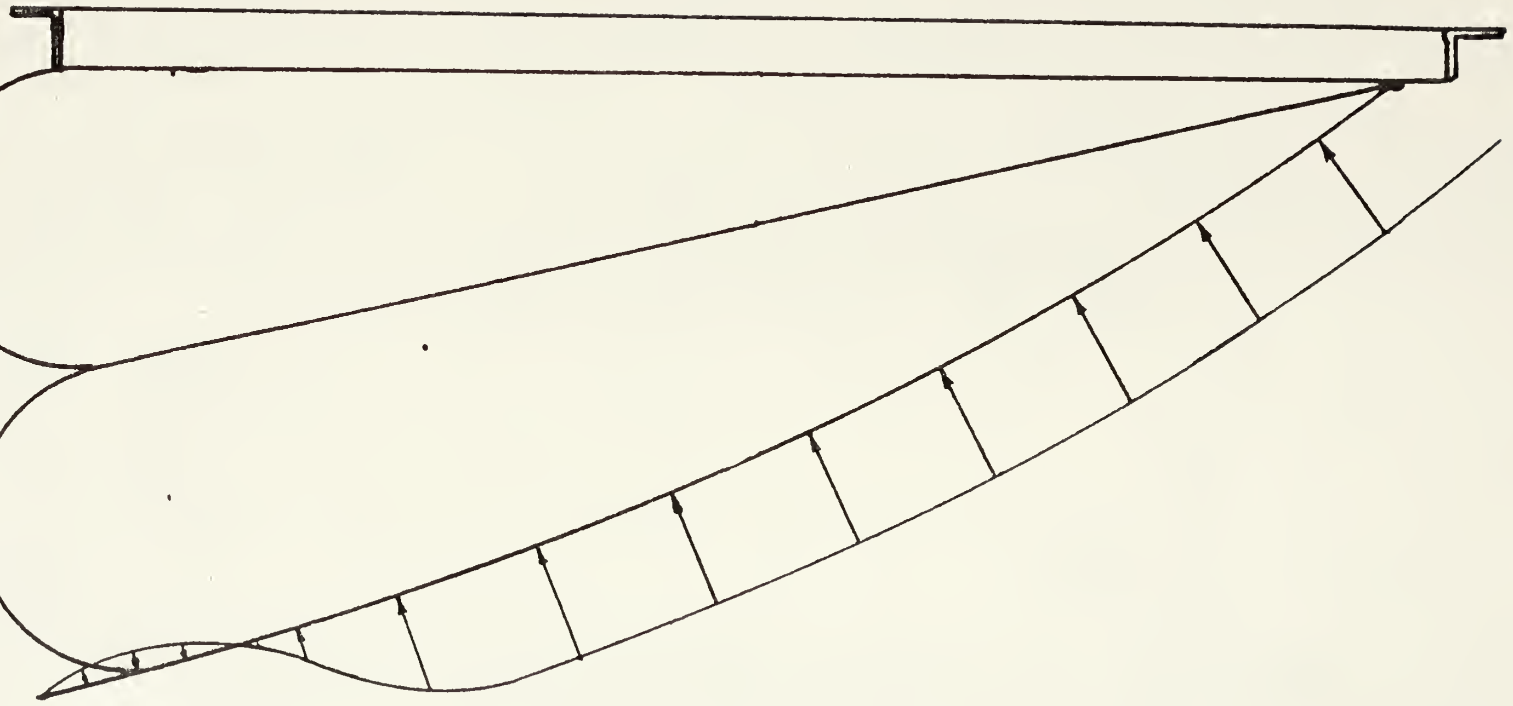

Figure 9 - PRESSURE DISTRIBUTION ON THE FORWARD FACE OF THE REAR SEAL

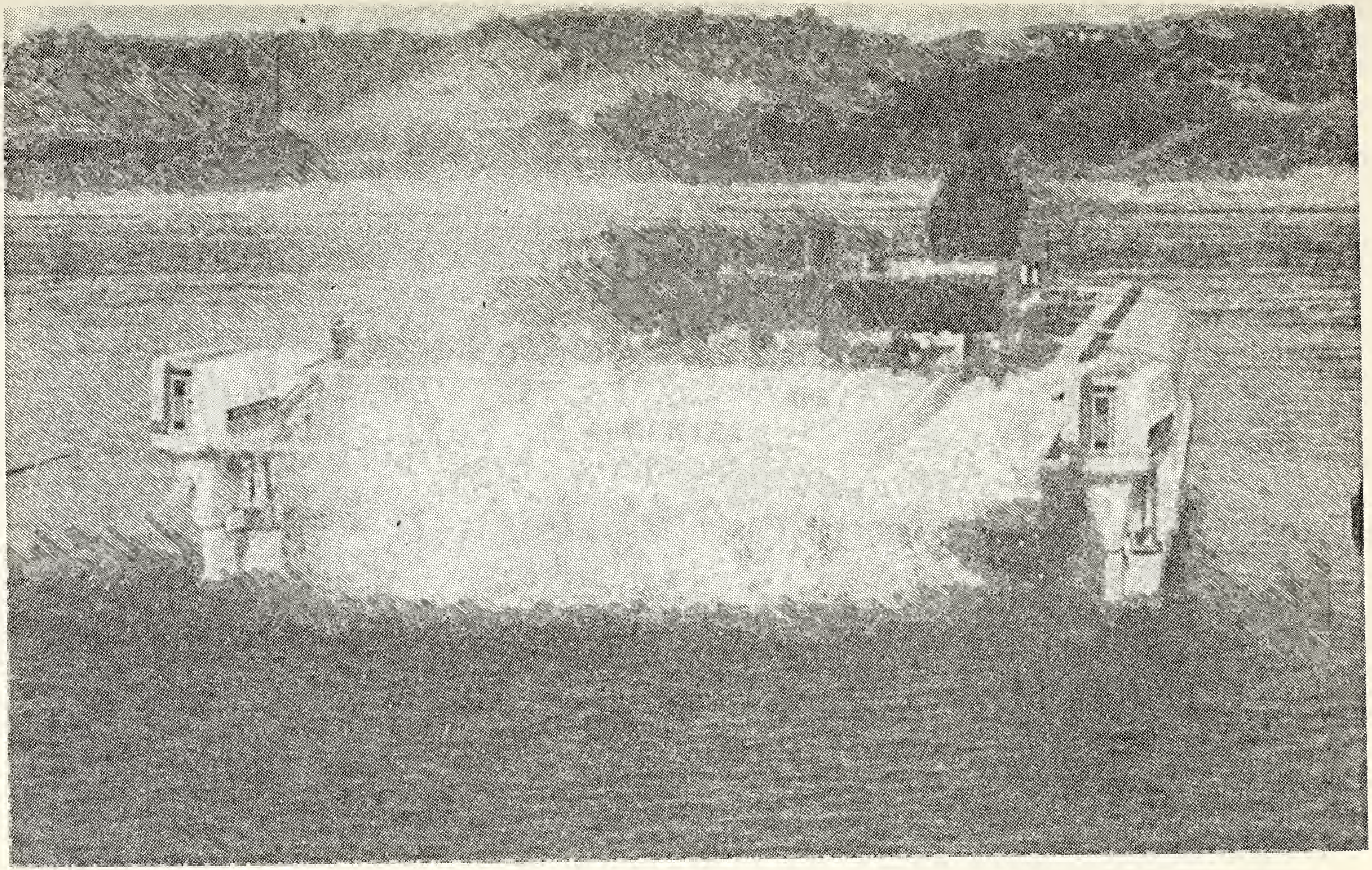

Figure 10 - XR-3 VENTING FROM BENEATH THE STERN SEAL

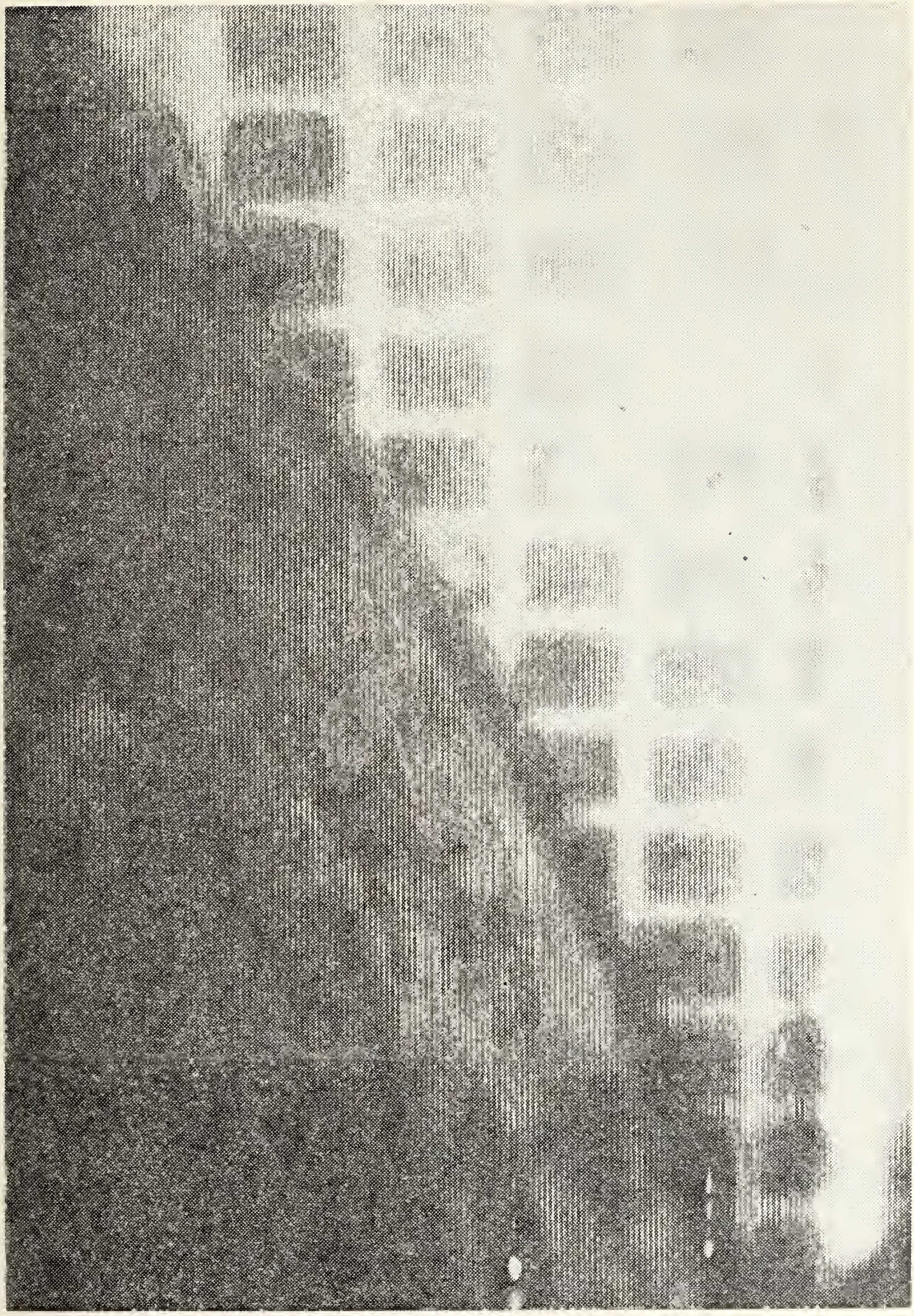

Figure 11 - TV PICTURE OF STERN SEAL

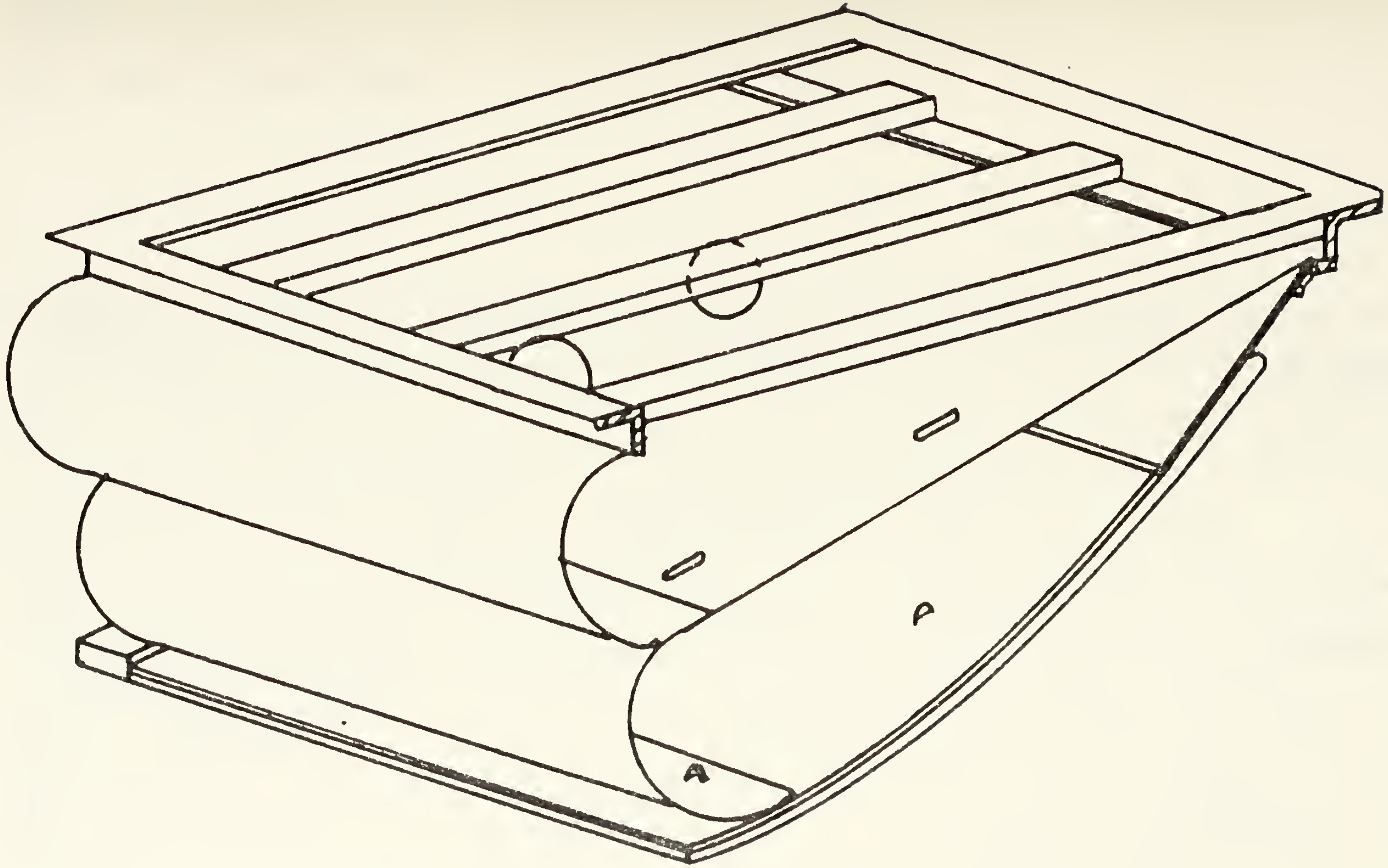

Figure 12 - STERN SEAL, PORT HALF

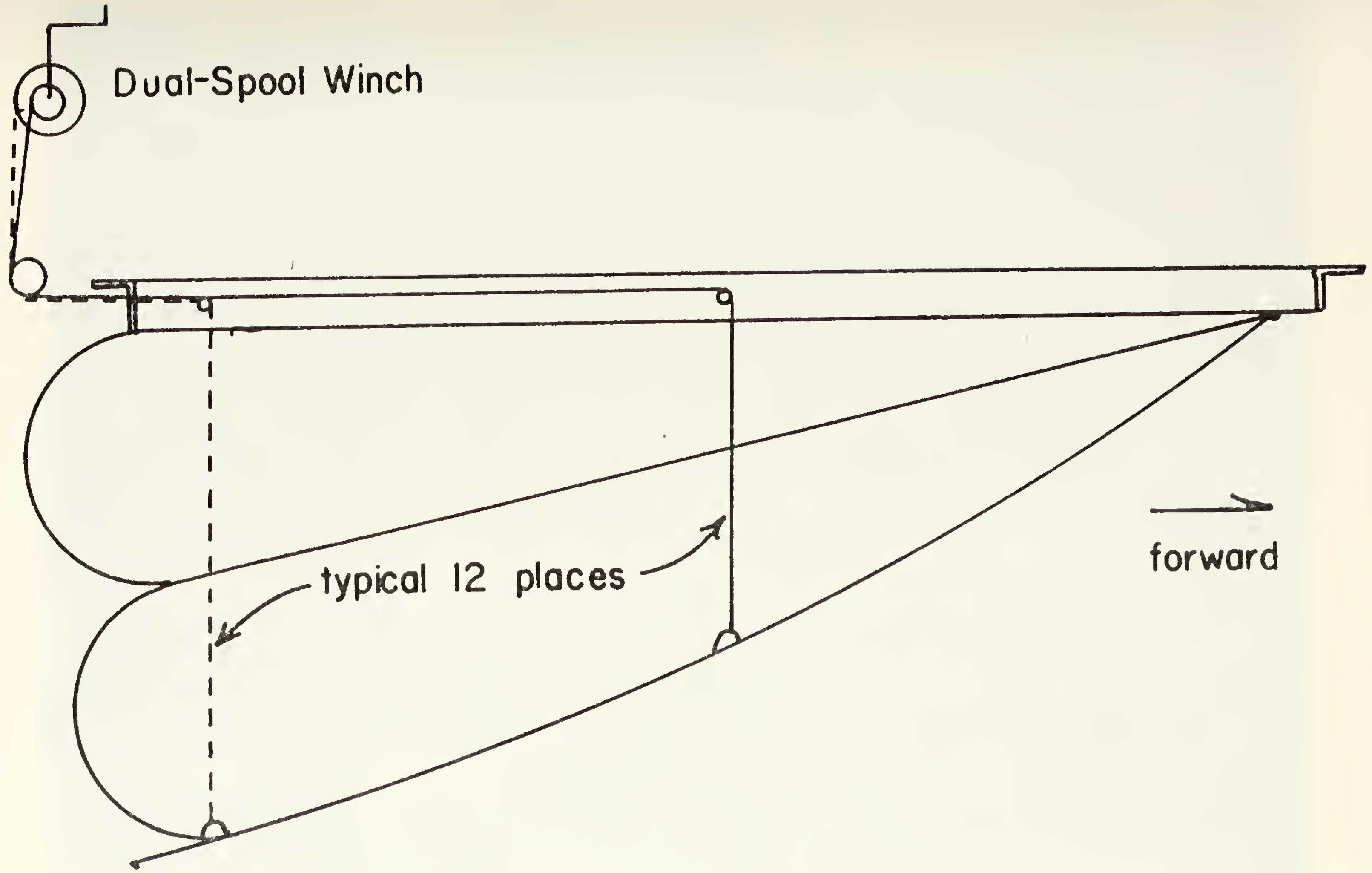

Figure 13 - STERN SEAL-SHOWING RIGGING OF POSITION CONTROL CABLES

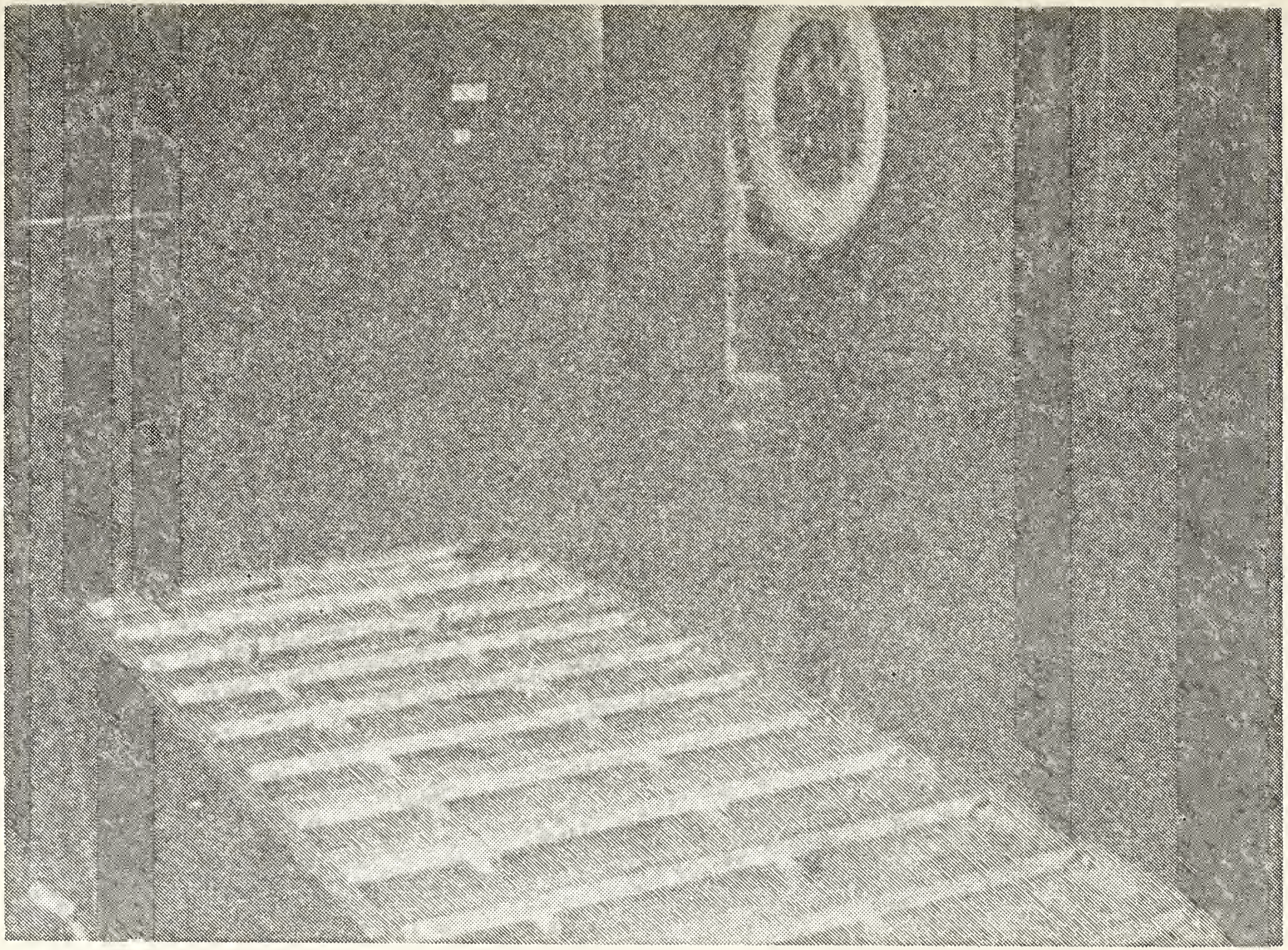

Figure 14 - STERN SEAL - SHOWING ATHWARTSHIP STIFFENERS

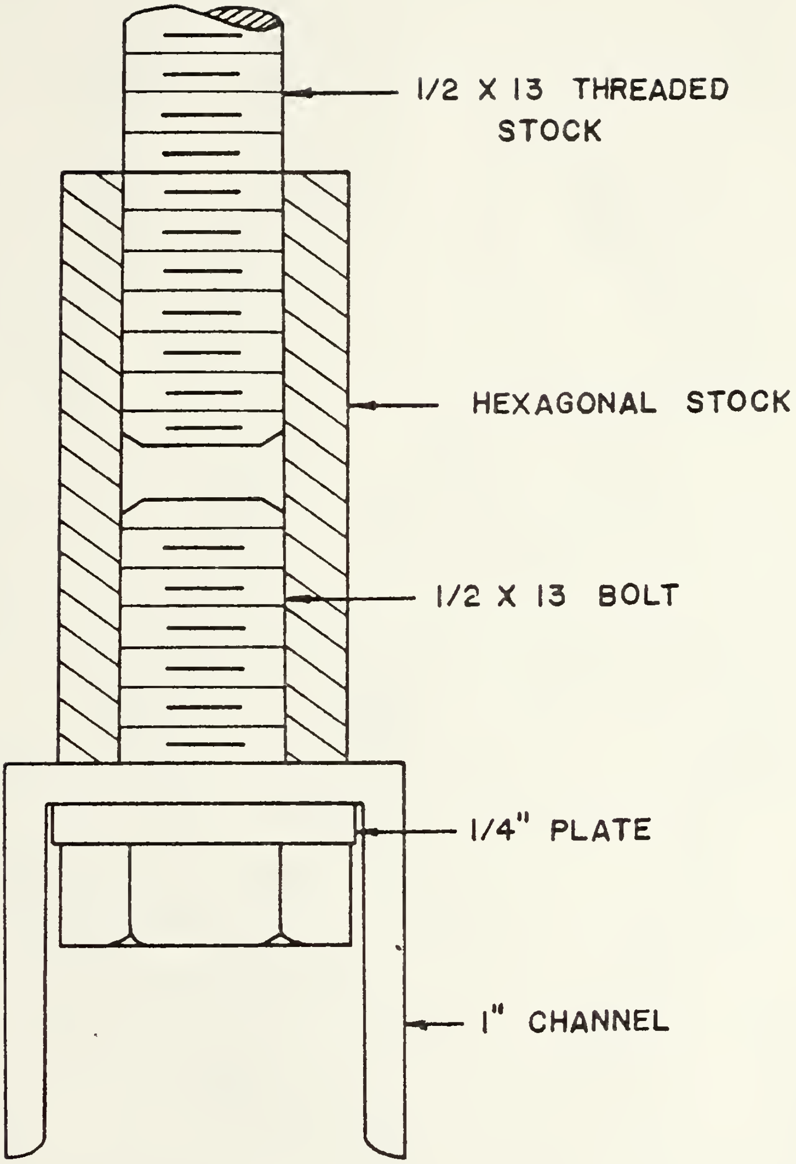

Figure 15 - LIFT LOAD CELL ATTACHMENT POINT

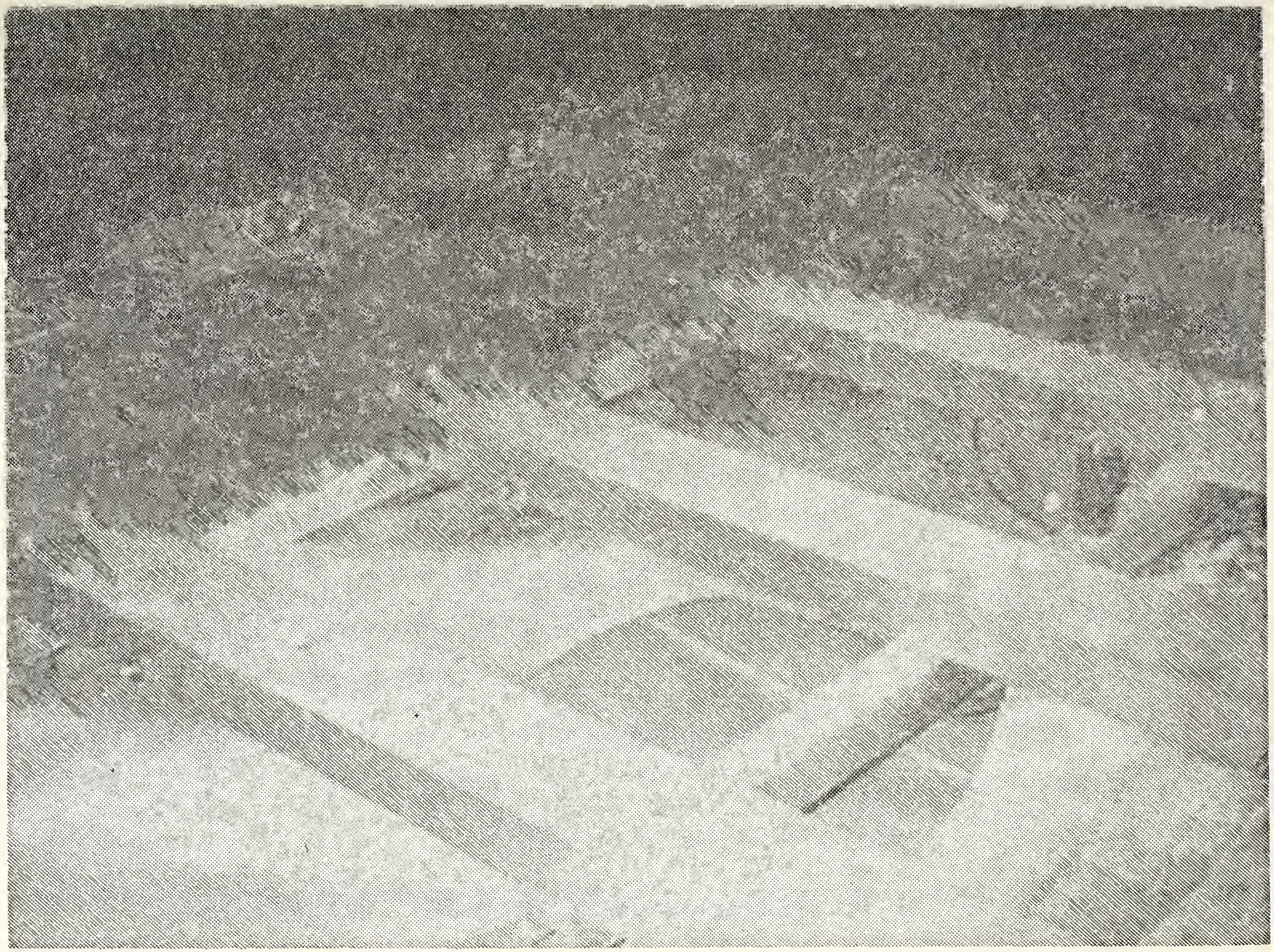

Figure 16 - LIFT LOAD CELL ATTACHMENT POINTS

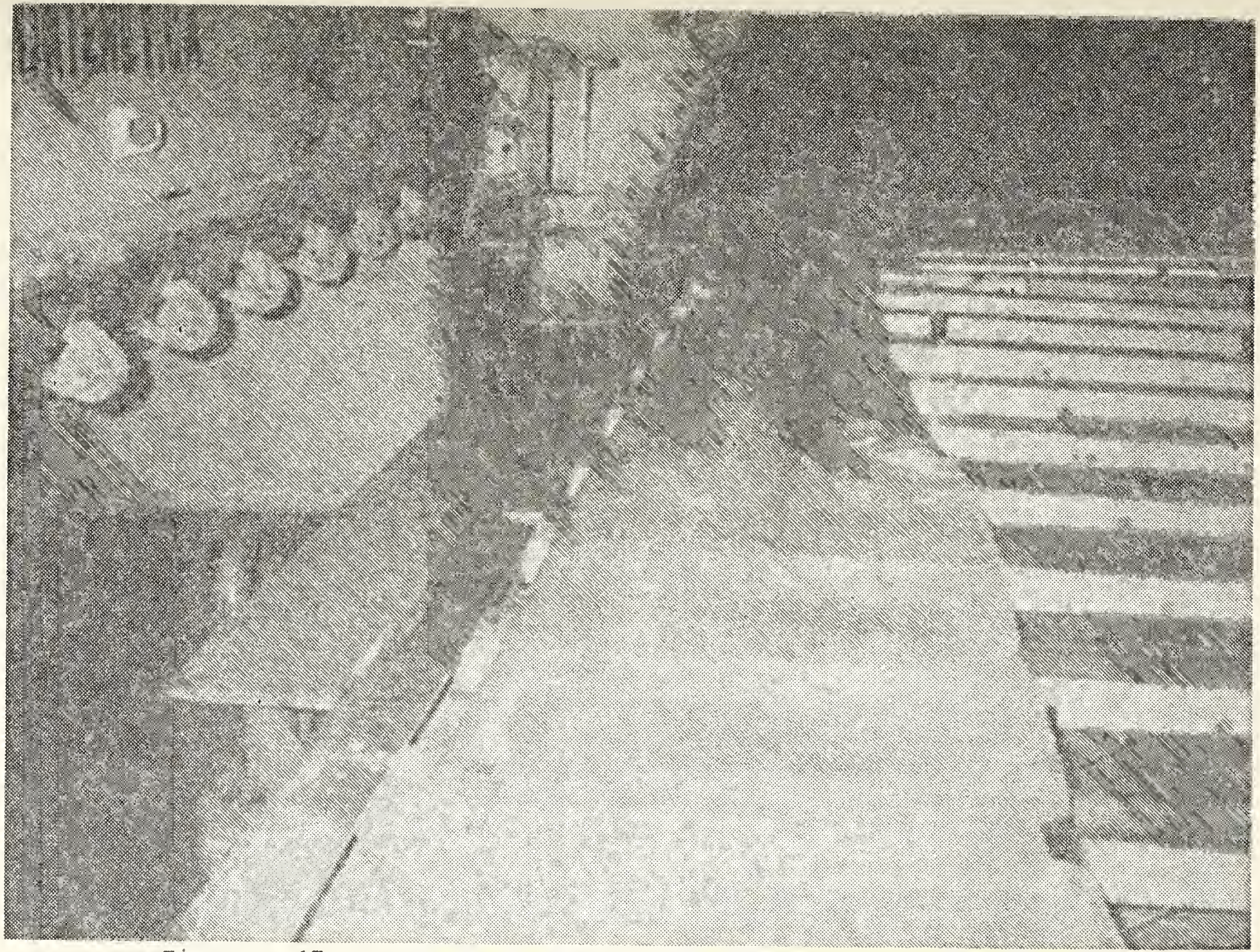

Figure 17 - LEADING EDGE OF STERN SEAL SHOWING PRESSURE SEALING PLASTIC SHEET

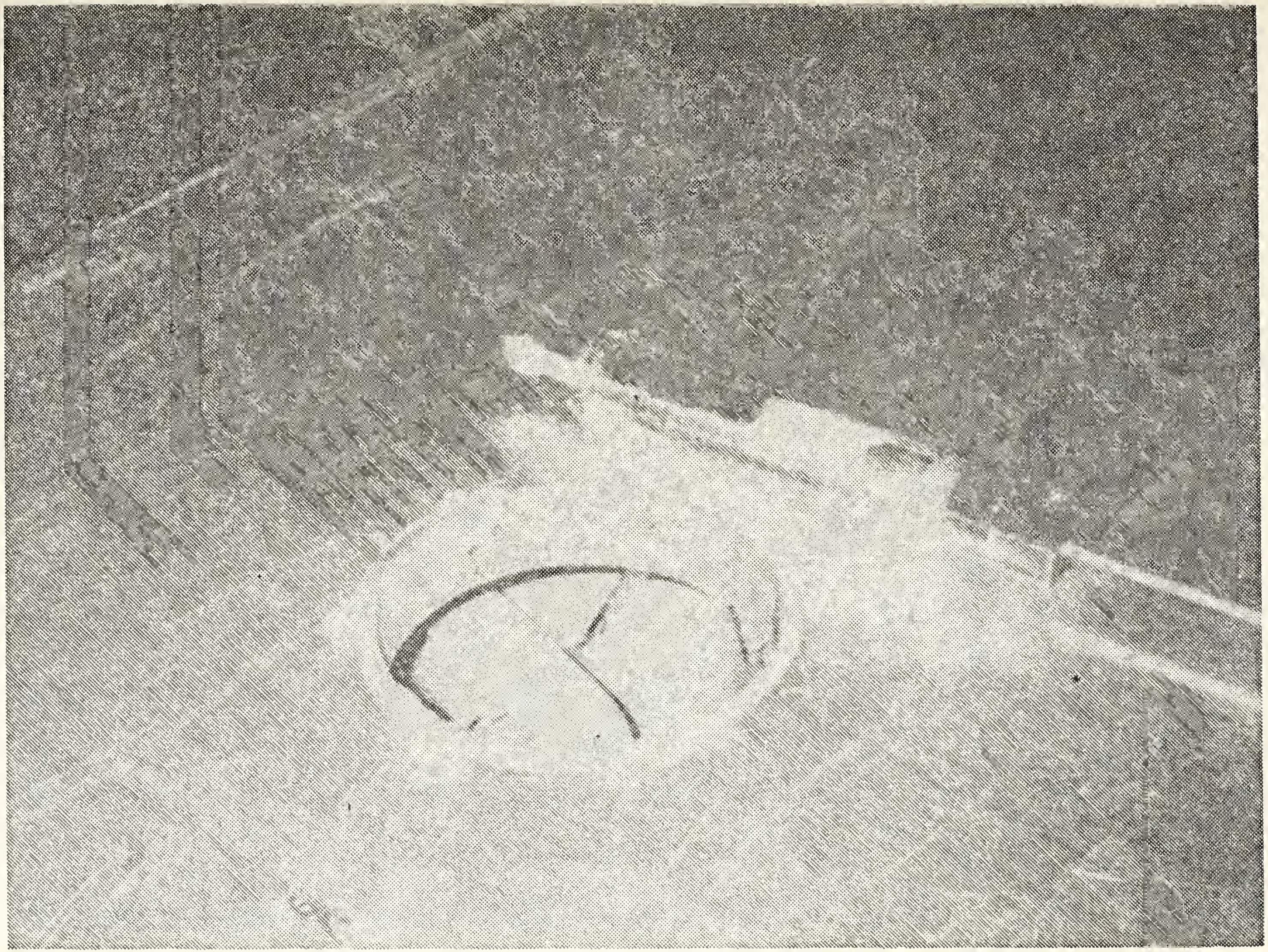

Figure 18 - STERN SEAL SHOWING UPPER SEALING PLATE AND AIR ACCESS HOLE

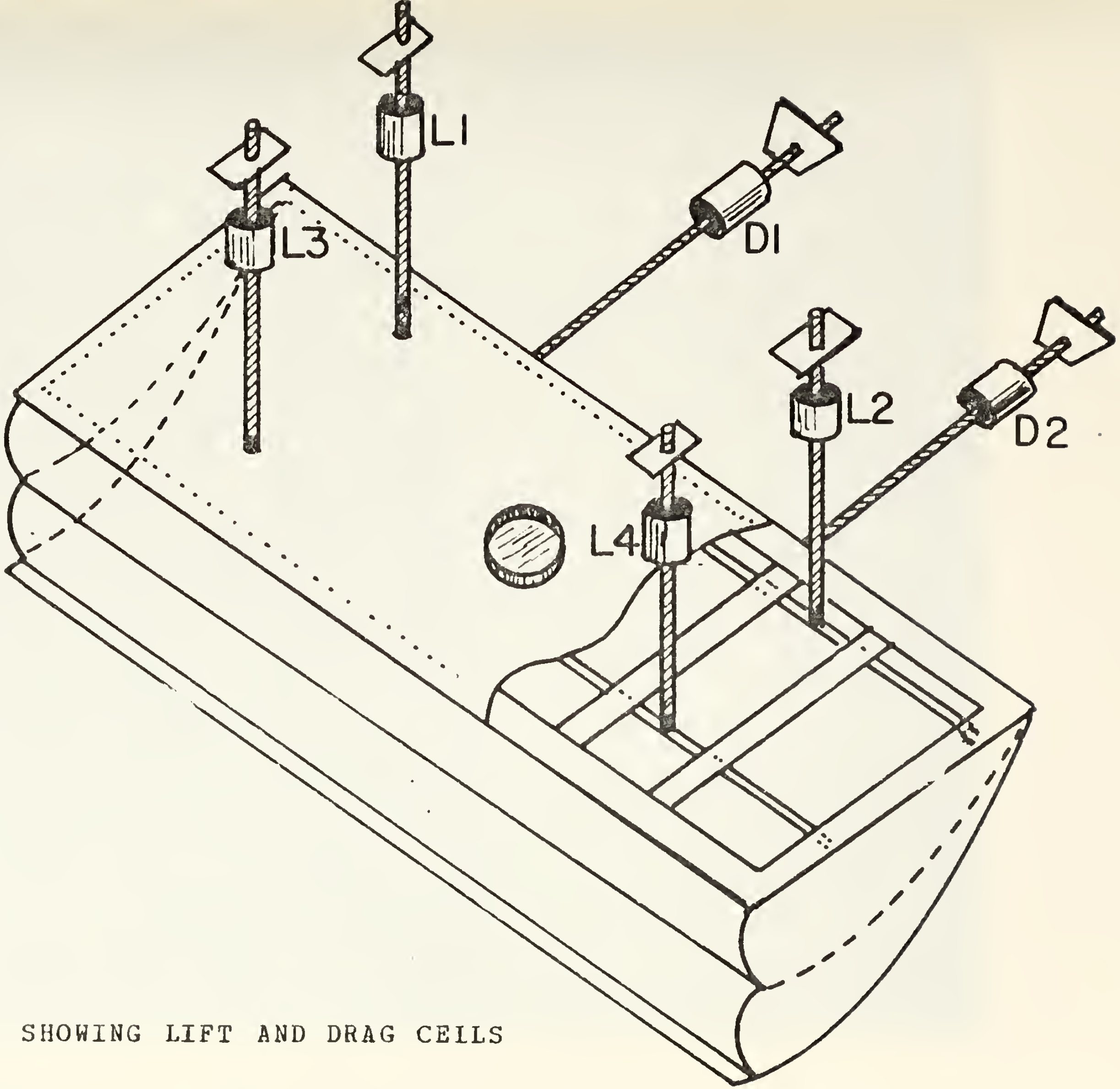

Figure 19 - STERN SEAL SHOWING LIFT AND DRAG CELLS

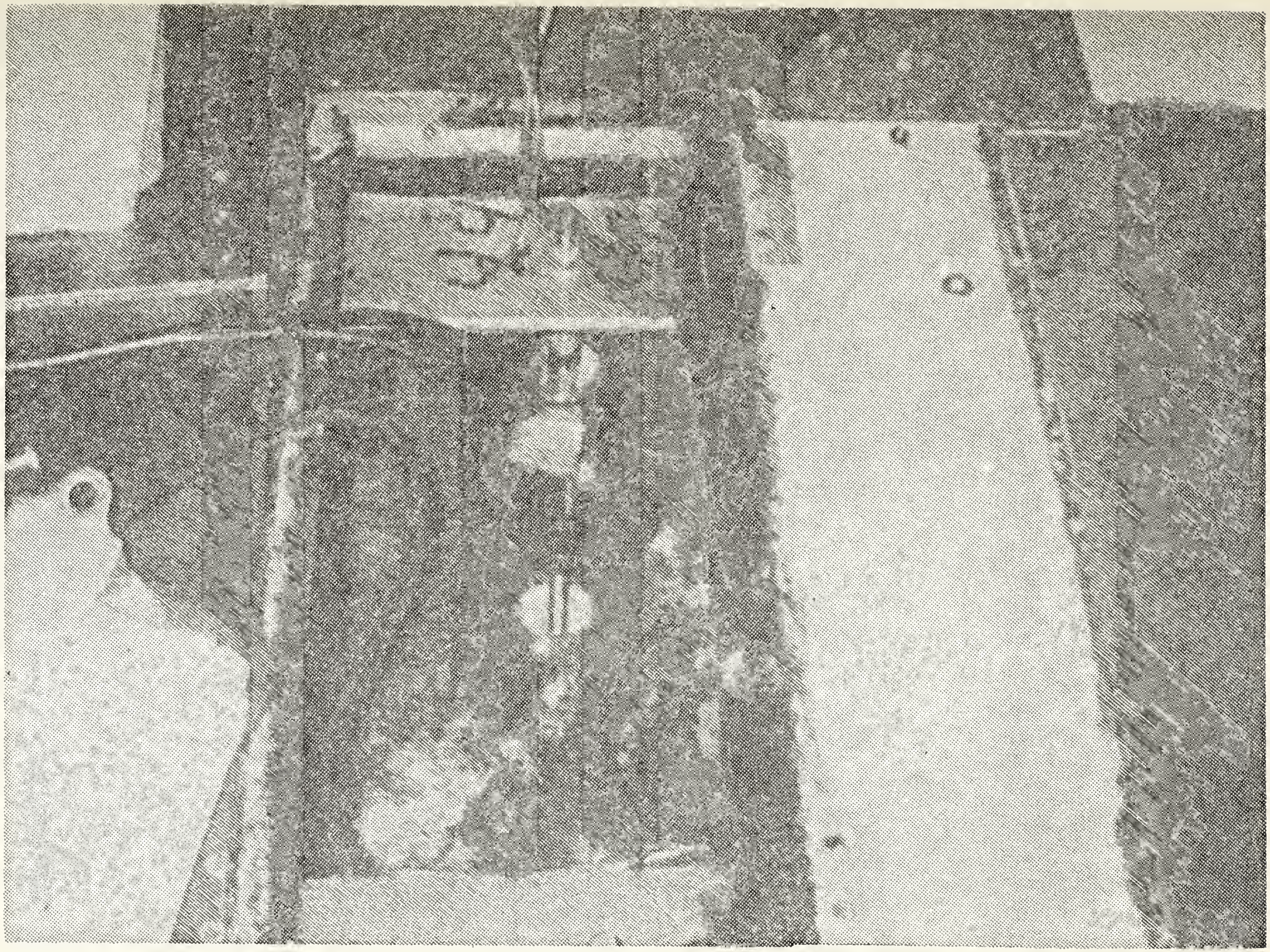

Figure 20 - LIFT LOAD CELL - INSTALLED

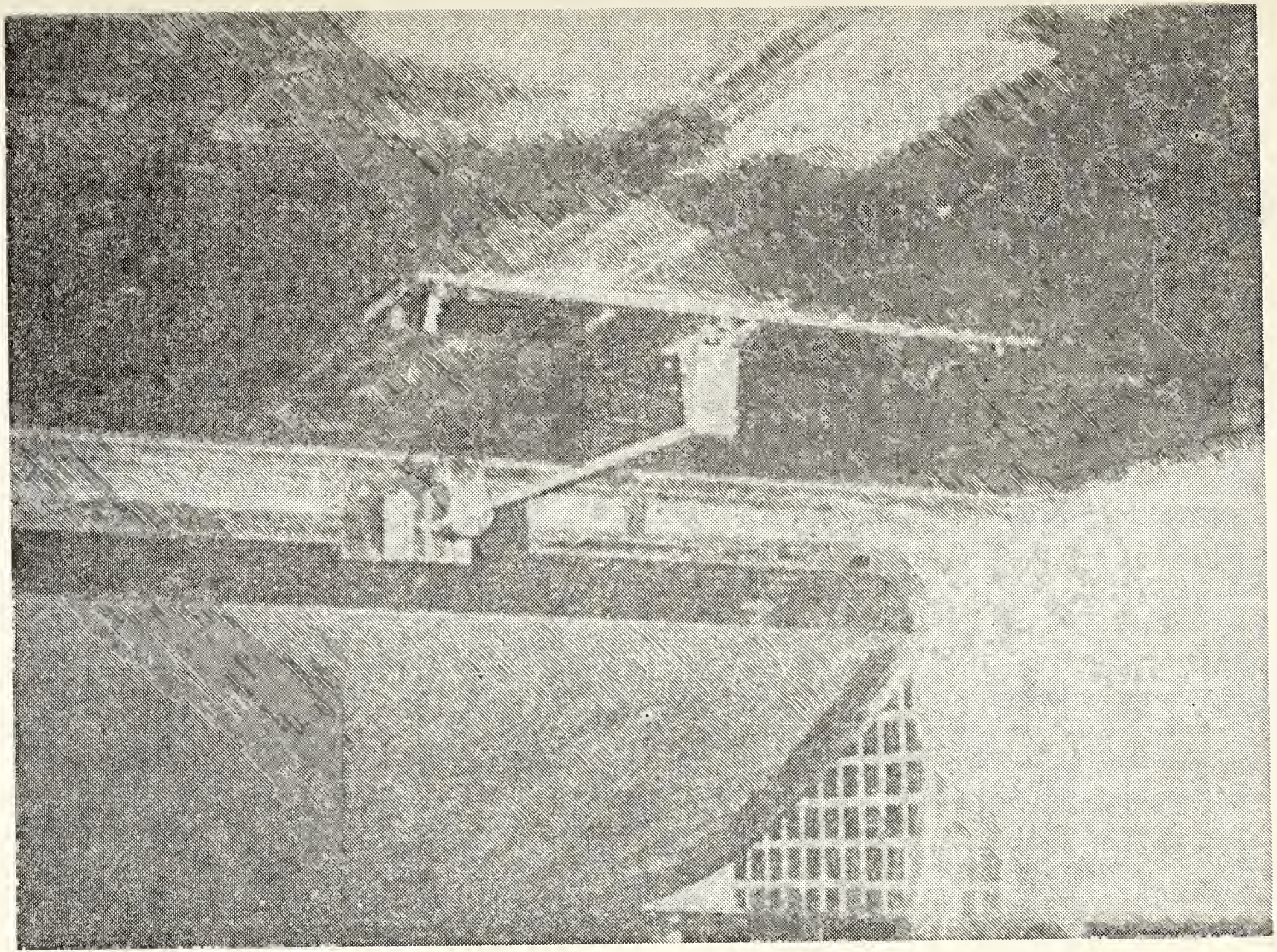

Figure 21 - DRAG LOAD CELL - INSTALLED

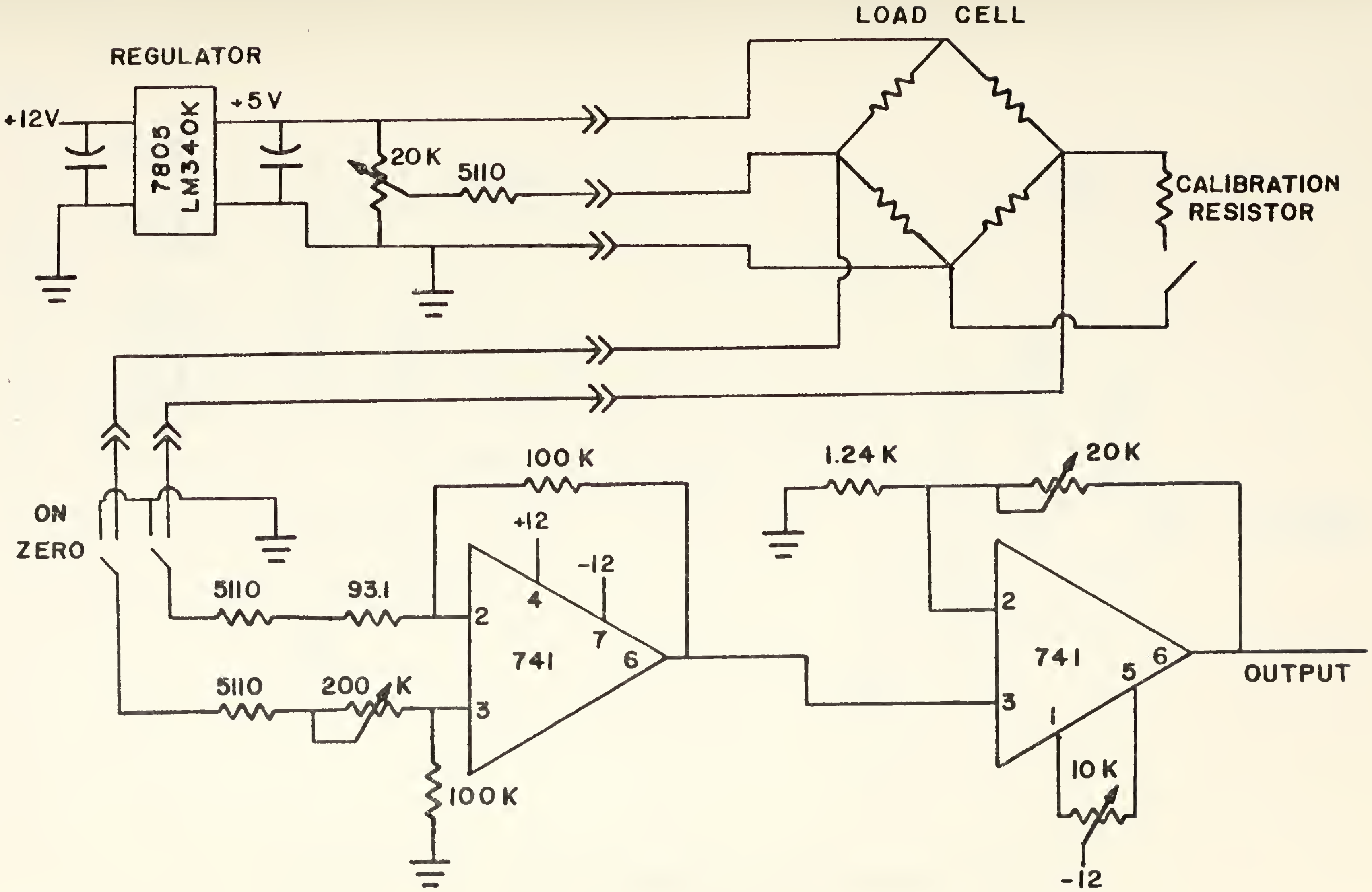

Figure 22 - LOAD CELL CIRCUIT

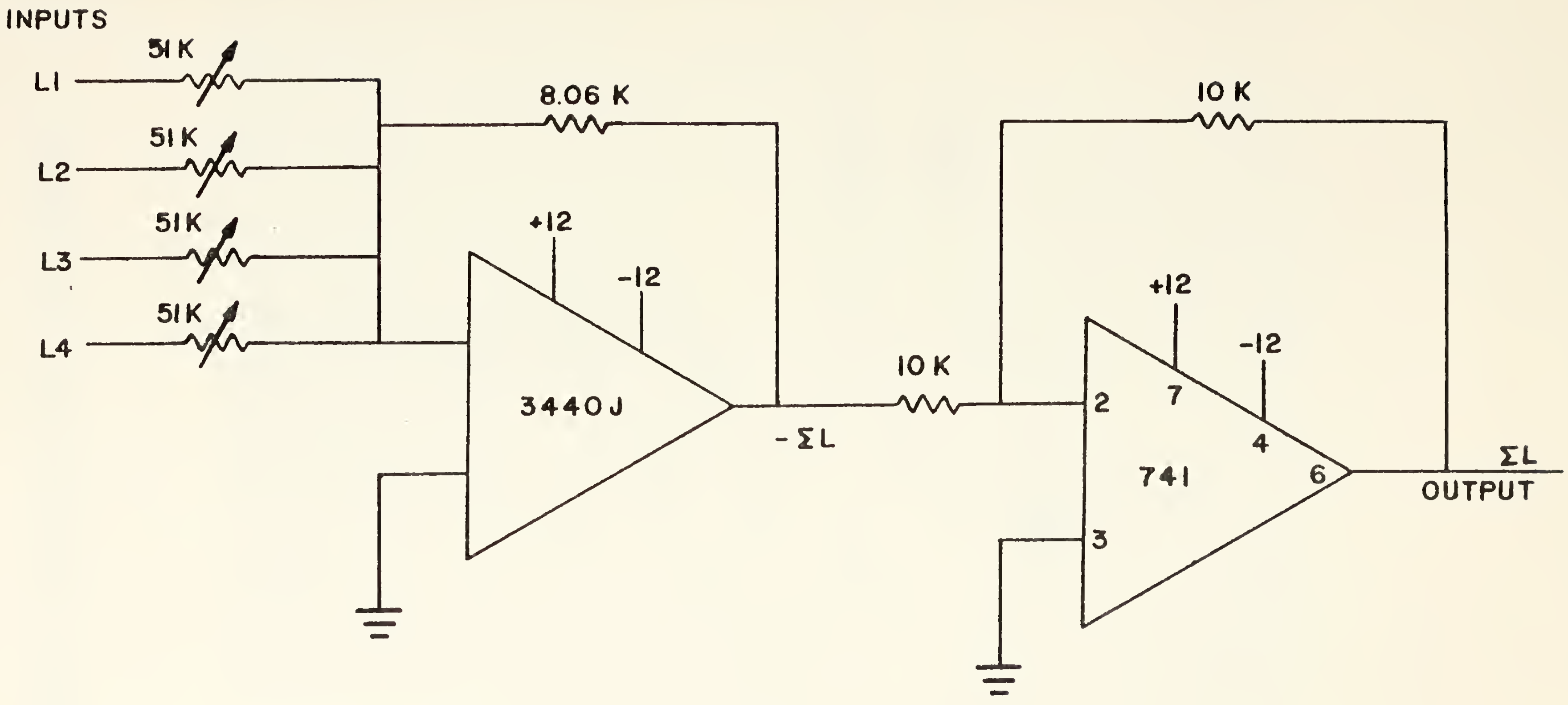

Figure 23 - LIFT SUMMATION AND INVERSION CIRCUIT

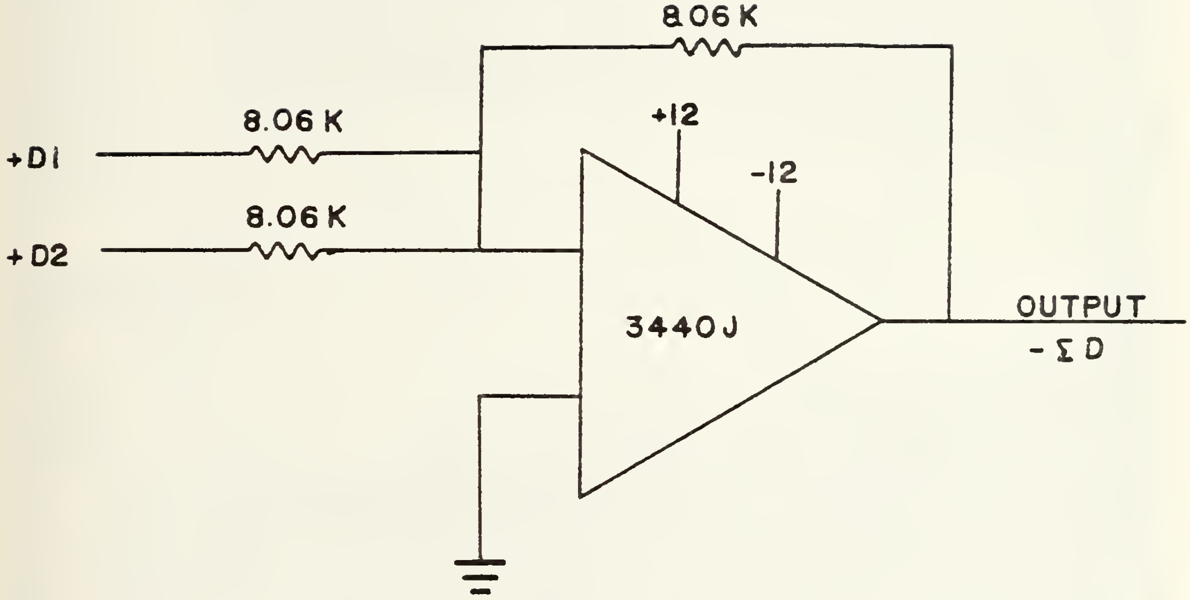

Figure 24 - DRAG SUMMATION CIRCUIT

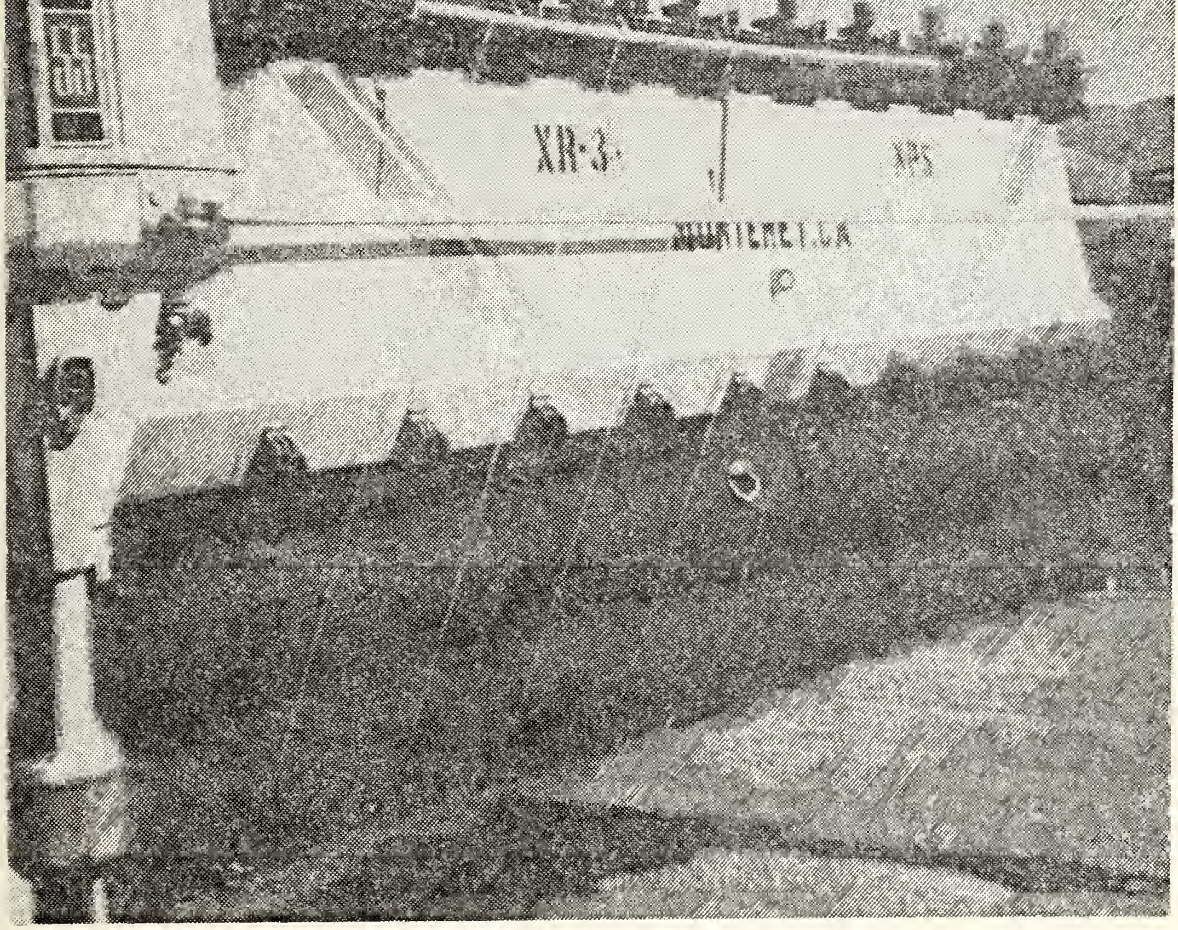

Figure 25 - SEAL POSITION MEASUREMENT SYSTEM - REAR VIEW

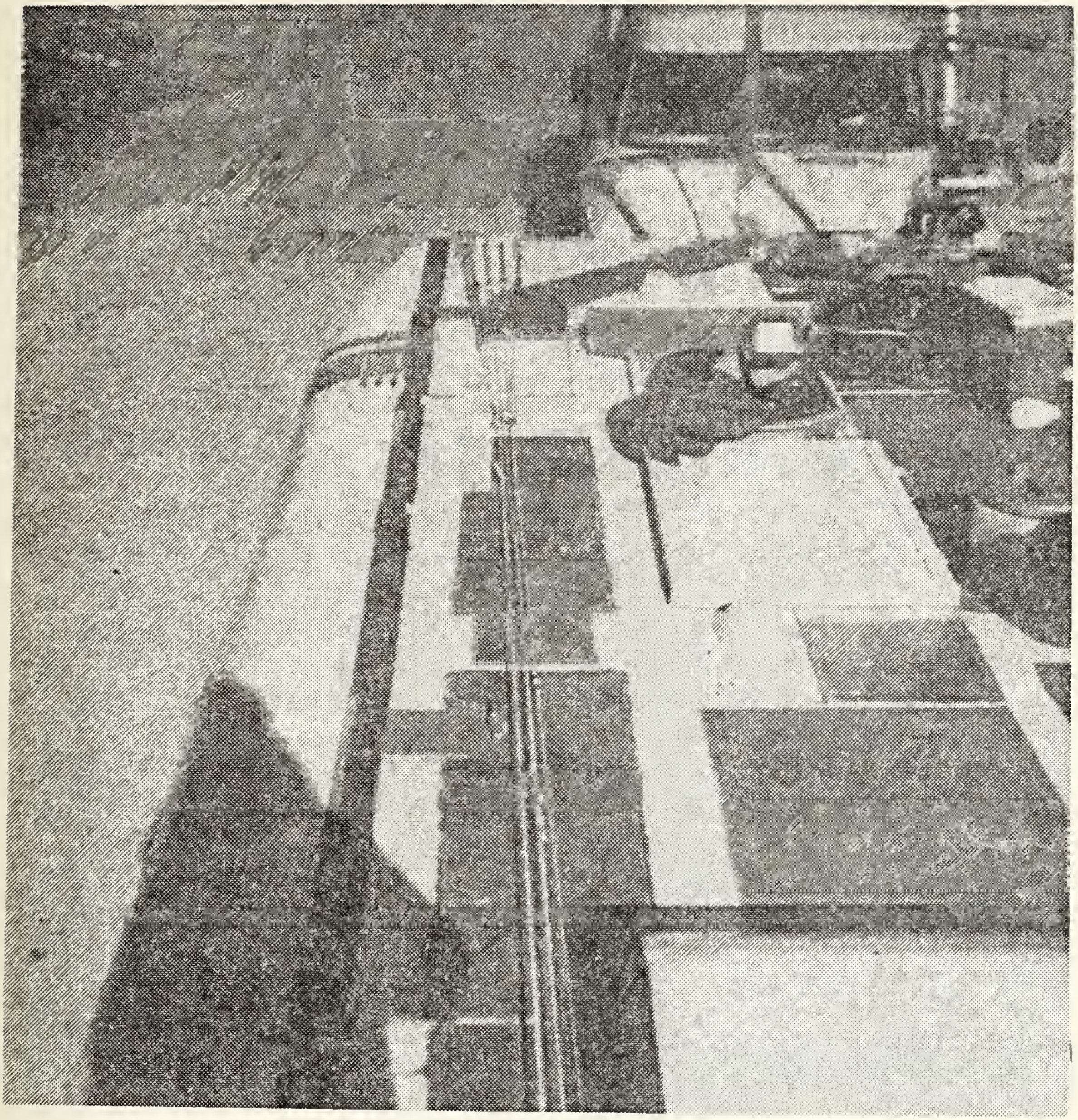

Figure 26 - SEAL POSITION MEASUREMENT SYSTEM - DECK VIEW

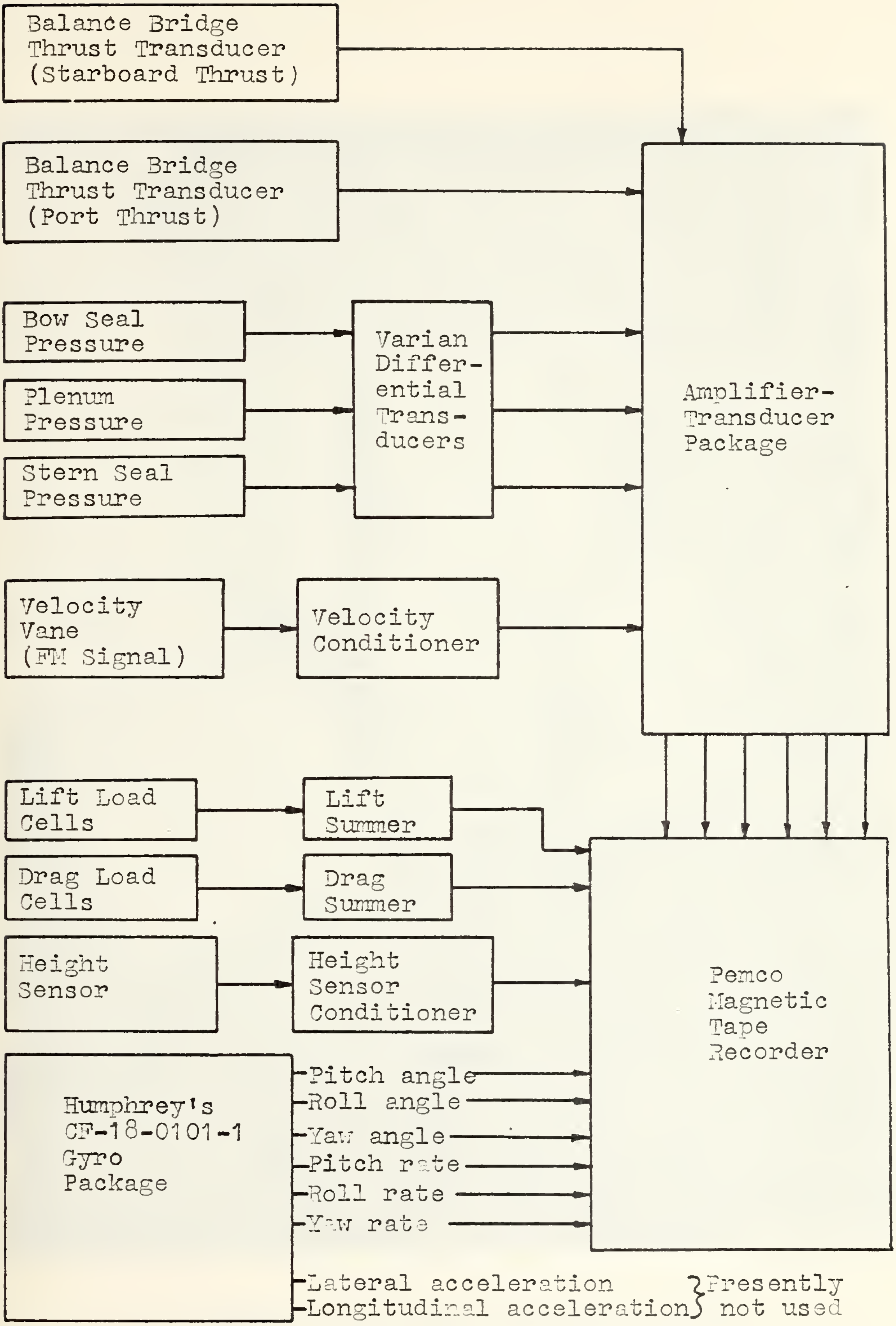
Balance Bridge Thrust Transducer (Starboard Thrust)
Balance Bridge Thrust Transducer (Port Thrust)
Bow Seal Pressure
Plenum Pressure
Stern Seal Pressure
Varian Differential Transducers
Amplifier-Transducer Package
Velocity Vane (FM Signal)
Velocity Conditioner
Lift Load Cells
Lift Summer
Drag Load Cells
Drag Summer
Height Sensor
Height Sensor Conditioner
Pemco Magnetic Tape Recorder
Humphrey's CF-18-0101-1 Gyro Package
Pitch angle
Roll angle
Yaw angle
Pitch rate
Roll rate
Yaw rate
Lateral acceleration
Longitudinal acceleration
Presently not used

Figure 27 - DATA ACQUISITION SYSTEM

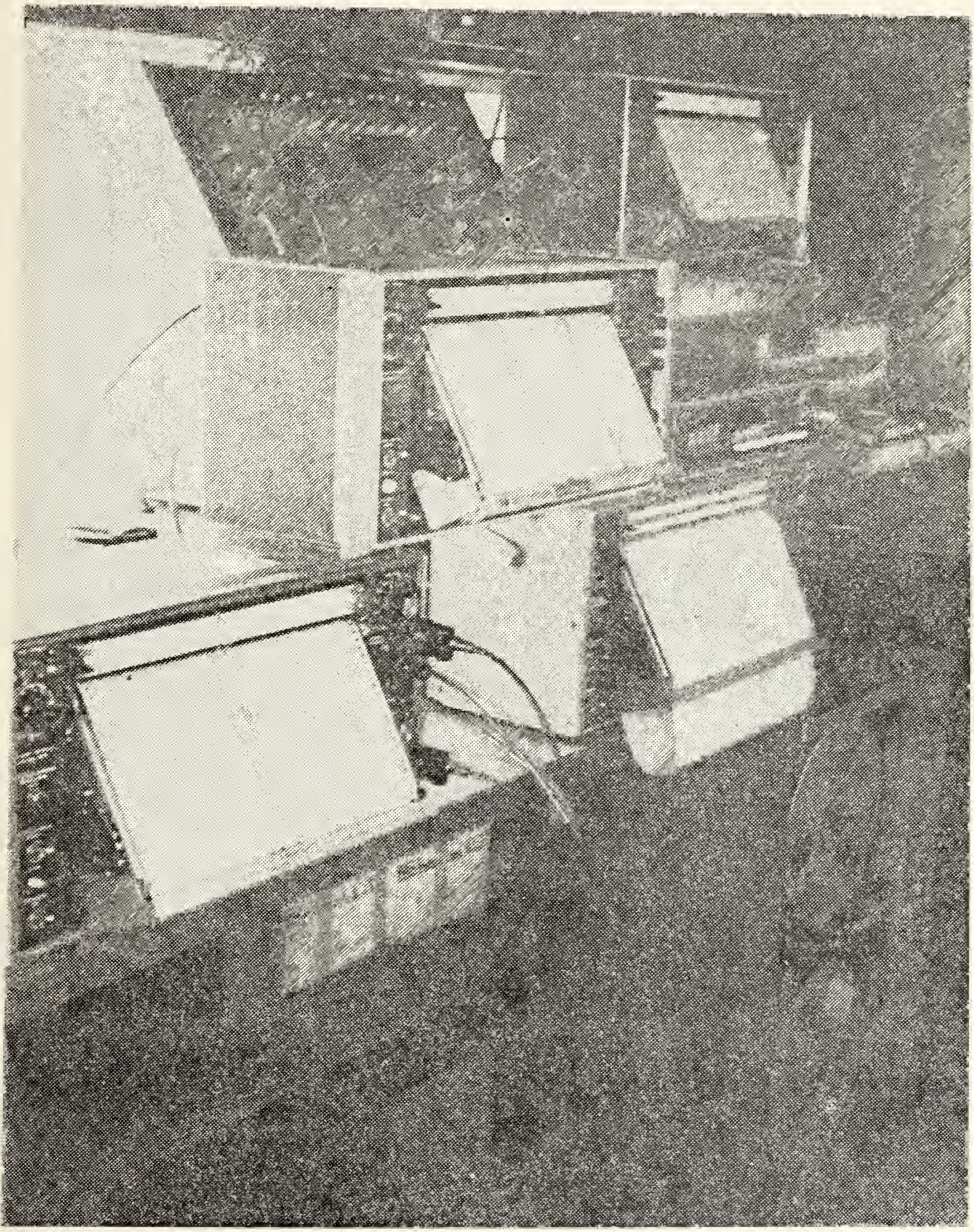

Figure 28 - DATA REDUCTION SYSTEM

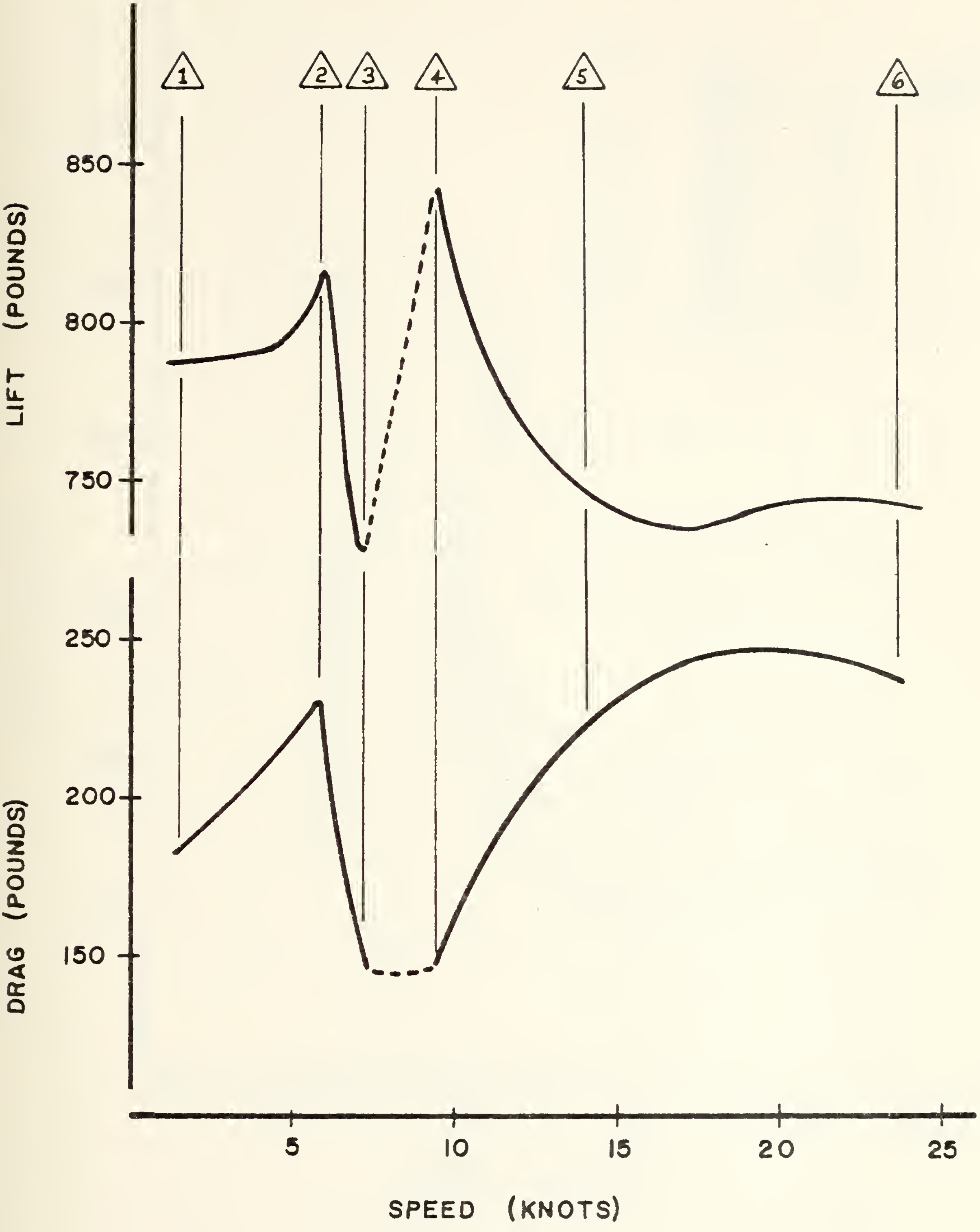

Figure 29 - GENERAL LIFT AND DRAG CURVES

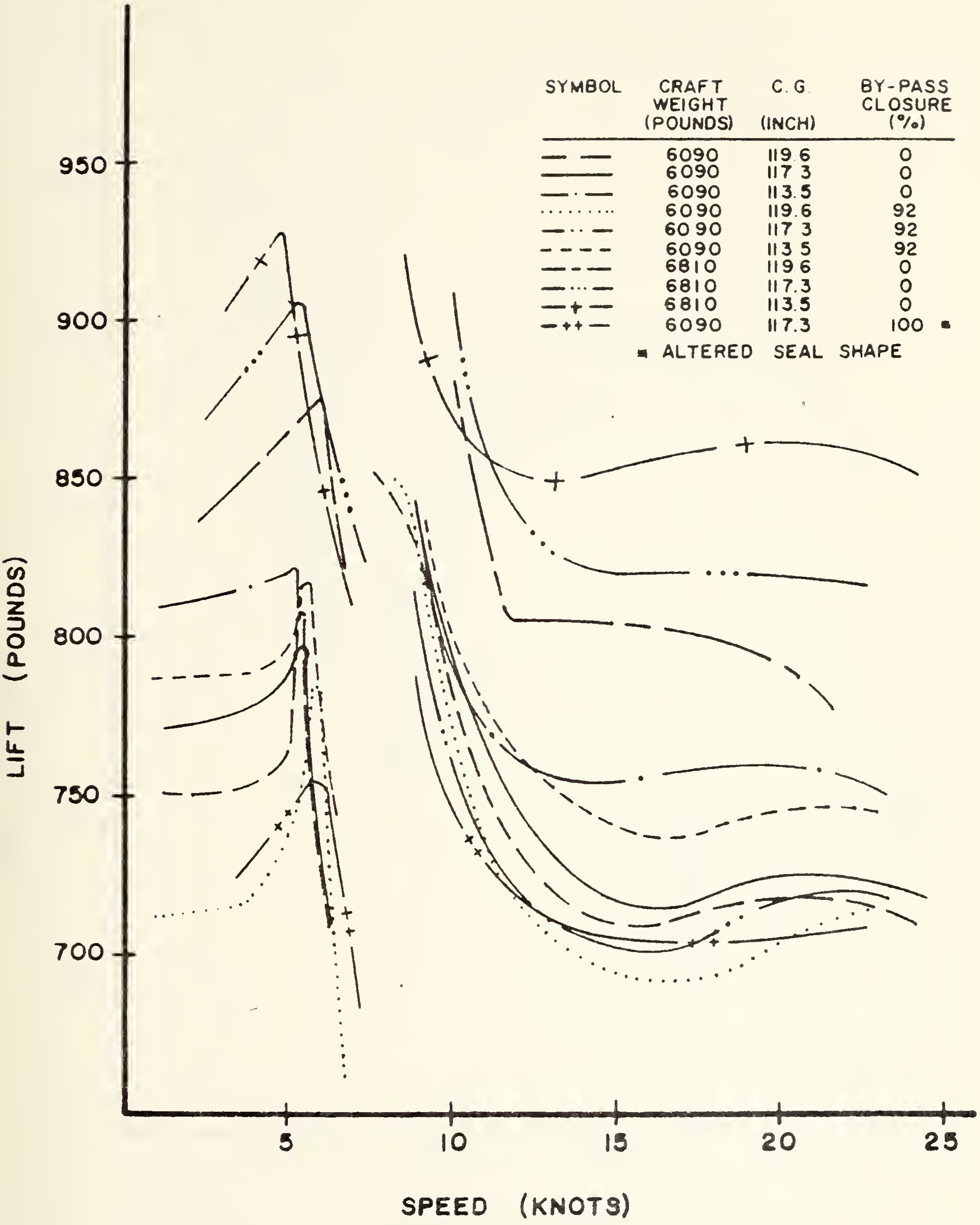

Figure 30 - LIFT SUMMARY

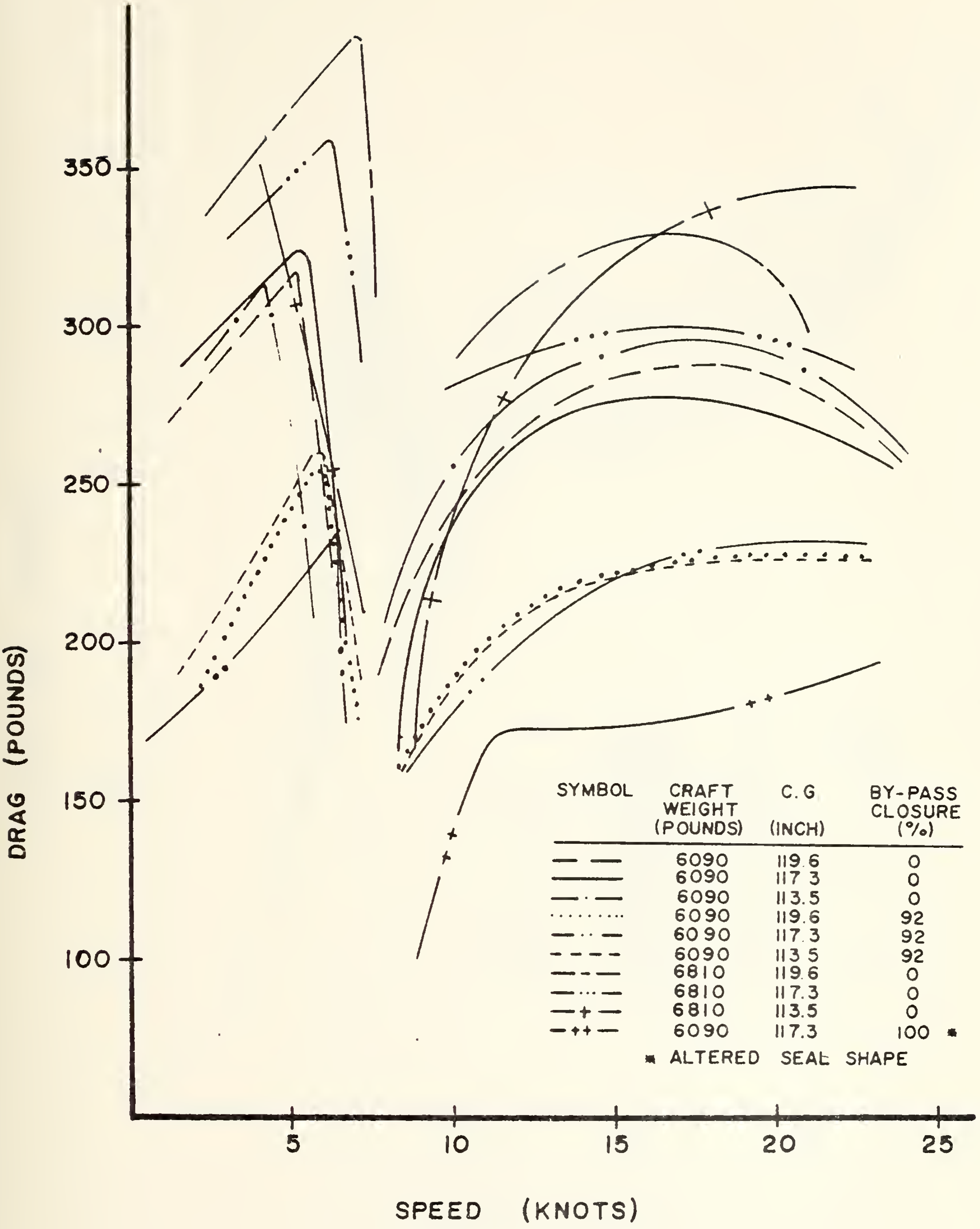

Figure 31 - DRAG SUMMARY

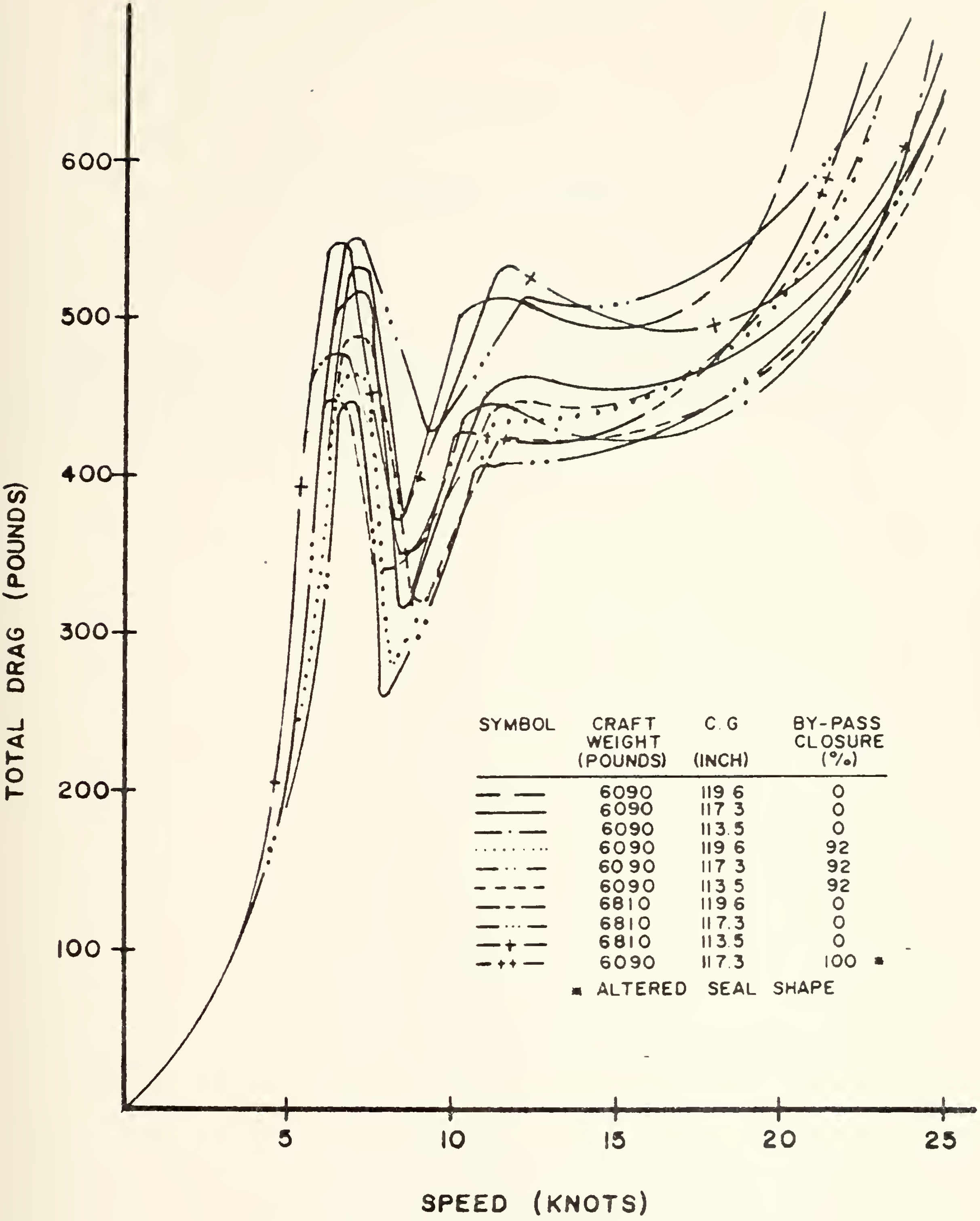

Figure 32 - TOTAL DRAG SUMMARY

APPENDIX A

TABULAR RESULTS

This appendix contains all data obtained during this investigation arranged in the same order as the tables on the summary plots.

TABLE 1

Testcraft Weight - 6090 Pounds
Center of Gravity - 119.6 Inches
By-pass Closed 0.0 Percent

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
02.1	028	751	279
02.4	072	751	285
02.7	105	751	292
03.4	160	751	298
04.6	216	760	307
05.1	315	778	310
05.2	339	760	304
05.4	329	752	280
05.6	265	808	345
05.7	421	730	304
07.6	345	850	201
08.7	358	826	212
09.1	375	816	241
09.8	395	822	242
10.5	423	750	254
11.5	436	721	269
11.5	452	752	255
14.2	438	708	274
14.6	462	712	270
15.0	445	708	278
16.7	477	710	295
18.1	486	709	281
19.0	500	718	285
20.2	528	715	281

TABLE 1 (continued)

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
20.3	520	722	294
21.0	564	712	280
22.0	655	700	260
22.5	587	722	267
23.5	645	720	250

TABLE 2

Testcraft Weight - 6090 Pounds
Center of Gravity - 117.3 Inches
By-pass Closed 0.0 Percent

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
03.0	148	779	315
03.1	085	709	305
03.6	162	780	310
03.9	208	770	310
04.5	209	763	315
05.0	315	785	300
05.1	385	789	335
05.2	337	789	295
05.2	348	792	297
05.2	347	774	285
05.3	380	769	285
05.4	435	754	270
05.5	405	732	278
05.5	465	749	268
05.6	432	759	277
05.7	478	746	277
05.7	482	730	280
05.8	498	744	282
06.4	440	740	310
06.8	517	739	300
08.3	320	840	165
08.3	345	829	240
09.3	395	799	305
09.3	366	838	248

TABLE 2 (continued)

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
09.4	350	825	220
09.8	390	805	245
10.2	400	790	245
10.2	437	806	293
10.5	420	762	252
10.5	448	764	227
11.4	432	738	265
12.4	450	710	235
14.5	455	700	255
14.6	430	728	278
15.2	433	710	276
16.6	460	712	270
17.7	505	726	290
18.2	478	725	276
18.2	476	722	267
19.6	543	719	280
20.2	504	725	275
20.5	515	729	262
20.5	517	731	283
21.2	551	722	278
21.7	539	725	205
22.7	587	725	242
22.8	624	714	266
24.0	612	710	245

TABLE 3

Testcraft Weight - 6090 Pounds
Center of Gravity - 113.5 Inches
By-pass Closed 0.0 Percent

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
03.0	115	725	301
03.2	136	822	302
04.0	235	810	209
04.8	302	792	227
05.5	445	744	245
09.1	371	840	252
10.0	412	798	265
11.6	436	757	275
15.0	417	759	290
15.7	416	752	295
19.4	446	762	298
21.2	496	762	296
21.9	531	755	281
23.4	594	735	258

TABLE 4

Testcraft Weight - 6090 Pounds
Center of Gravity - 119.6 Inches
By-pass Closed 92 Percent

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
01.1	012	718	177
02.5	045	709	210
03.5	110	712	210
03.5	129	718	188
04.5	180	741	245
04.7	247	731	234
05.8	305	749	255
05.8	301	784	250
05.8	322	750	226
05.8	314	744	215
06.2	412	700	210
06.3	409	634	210
06.5	435	659	217
06.5	445	690	217
08.2	277	843	164
08.4	285	849	180
08.8	305	834	172
09.3	380	800	180
09.4	345	794	155
09.5	342	789	190
09.7	361	789	197
10.0	374	772	205
10.6	405	722	185
11.6	435	694	190

TABLE 4 (continued)

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
12.8	438	709	210
13.9	431	706	222
15.8	445	675	204
16.8	445	704	225
17.3	465	673	220
18.6	482	666	222
18.7	490	695	232
19.8	501	721	255
20.2	522	679	223
21.2	553	712	245
21.6	570	694	225
22.6	617	708	232
22.7	635	716	205

TABLE 5

Testcraft Weight - 6090 Pounds
Center of Gravity - 117.3 Inches
By-pass Closed 92 Percent

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
00.2	020	723	170
02.3	060	721	186
03.0	076	720	200
03.3	133	730	190
03.6	105	720	220
04.0	140	703	209
04.1	185	735	205
04.4	170	707	210
04.9	225	703	216
04.9	245	732	213
05.2	248	810	260
05.7	245	745	220
05.7	325	766	225
05.7	310	770	230
05.8	322	775	240
05.8	290	730	215
06.0	349	715	208
06.1	372	705	205
06.1	372	705	212
06.2	385	697	215
06.3	410	697	232
06.4	435	690	235
06.6	430	695	243
06.7	447	692	240

TABLE 5 (continued)

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
07.8	260	817	168
08.6	280	815	160
08.8	295	810	159
08.9	304	795	152
09.2	328	773	160
09.4	339	780	170
10.3	368	750	197
10.5	404	746	176
11.6	430	706	186
12.1	395	720	225
13.8	400	708	235
15.4	445	692	196
16.2	410	710	235
17.1	458	696	210
18.5	435	720	255
18.8	481	711	229
20.0	482	736	250
20.2	468	720	245
21.5	495	720	240
21.8	532	722	240
22.4	512	715	240
23.1	594	720	228
23.5	570	710	225

TABLE 6

Testcraft Weight - 6090 Pounds
Center of Gravity - 113.5 Inches
By-pass Closed 92 Percent

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
02.0	032	790	218
02.3	042	782	202
03.1	085	787	222
03.2	090	790	218
04.0	145	790	232
04.2	162	790	255
04.6	215	780	245
05.4	262	820	225
05.6	302	782	198
06.0	390	770	232
06.2	412	755	228
06.5	416	750	228
06.7	482	752	238
09.5	342	835	190
10.4	399	772	192
11.3	425	742	188
12.5	425	760	225
14.2	418	760	225
15.7	425	747	225
16.2	438	718	200
18.9	475	726	212
20.7	471	755	248
22.0	513	749	237
23.7	565	730	208

TABLE 7

Testcraft Weight - 6810 Pounds
Center of Gravity - 119.6 Inches
By-pass Closed 0.0 Percent

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
02.1	041	843	340
03.5	120	855	349
03.6	165	845	340
04.1	163	866	375
04.5	252	851	370
05.6	318	872	381
05.7	345	868	378
06.0	419	862	386
06.1	458	850	378
06.2	433	860	382
06.4	530	832	382
06.9	520	869	398
10.2	500	870	292
11.7	515	805	300
16.0	491	808	345
15.7	498	805	332
18.2	530	801	330
20.2	624	792	300
21.1	662	783	296

TABLE 8

Testcraft Weight - 6810 Pounds
Center of Gravity - 117.3 Inches
By-pass Closed 0.0 Percent

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
03.4	106	880	333
03.5	110	880	335
03.9	152	892	380
04.1	167	895	346
05.1	272	900	350
05.5	312	885	358
05.6	365	890	340
05.9	453	851	320
06.4	498	850	370
06.7	509	839	318
06.8	550	853	340
10.0	445	900	300
11.6	495	830	288
12.1	512	824	285
15.6	511	820	306
18.7	545	821	303
19.0	575	840	300
21.1	563	821	316
21.6	618	812	291

TABLE 9

Testcraft Weight - 6810 Pounds
Center of Gravity - 113.5 Inches
By-pass Closed 0.0 Percent

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
03.2	084	918	348
03.8	170	914	332
04.0	160	915	354
04.4	224	893	330
04.5	250	902	311
05.0	311	900	276
05.5	328	887	285
05.7	422	850	250
06.2	538	832	261
06.2	534	841	278
06.4	545	843	279
08.3	371	912	170
09.0	410	905	180
11.8	526	850	290
14.8	495	852	323
16.8	493	862	334
18.0	500	858	329
20.5	508	873	355
22.5	542	859	331
23.0	581	841	398

TABLE 10

Testcraft Weight - 6090 Pounds
Center of Gravity - 117.3 Inches
By-pass Closed 100 Percent

Modified seal shape

Speed (knots)	Total Drag (pounds)	Lift (pounds)	Seal Drag (pounds)
02.2	088	748	118
03.8	030	728	165
04.4	134	740	178
04.5	428	745	135
04.7	484	730	170
05.0	240	723	163
05.6	414	752	152
06.4	420	748	169
07.1	420	690	169
08.8	330	786	105
09.0	324	787	101
10.1	430	750	145
11.4	416	724	174
12.7	436	711	171
13.8	376	707	175
13.9	376	709	175
15.1	440	710	168
15.6	430	710	178
18.1	484	720	190
20.0	600	687	171
20.1	542	706	182
21.0	584	707	188
22.4	634	708	198

APPENDIX B

GRAPHICAL RESULTS

This appendix contains the individual graphs complete with data points used to construct the summary plots, figures 30 through 32.

The graphs correspond to the following conditions:

CONDITION NUMBER	TESTCRAFT WEIGHT (pounds)	C.G. (inches)	BY-PASS CLOSURE (percent)
1	6090	119.6	0
2	6090	117.3	0
3	6090	113.5	0
4	6090	119.6	92
5	6090	117.3	92
6	6090	113.5	92
7	6810	119.6	0
8	6810	117.3	0
9	6810	113.5	0
10	6090	117.3	100 *

* - modified seal shape

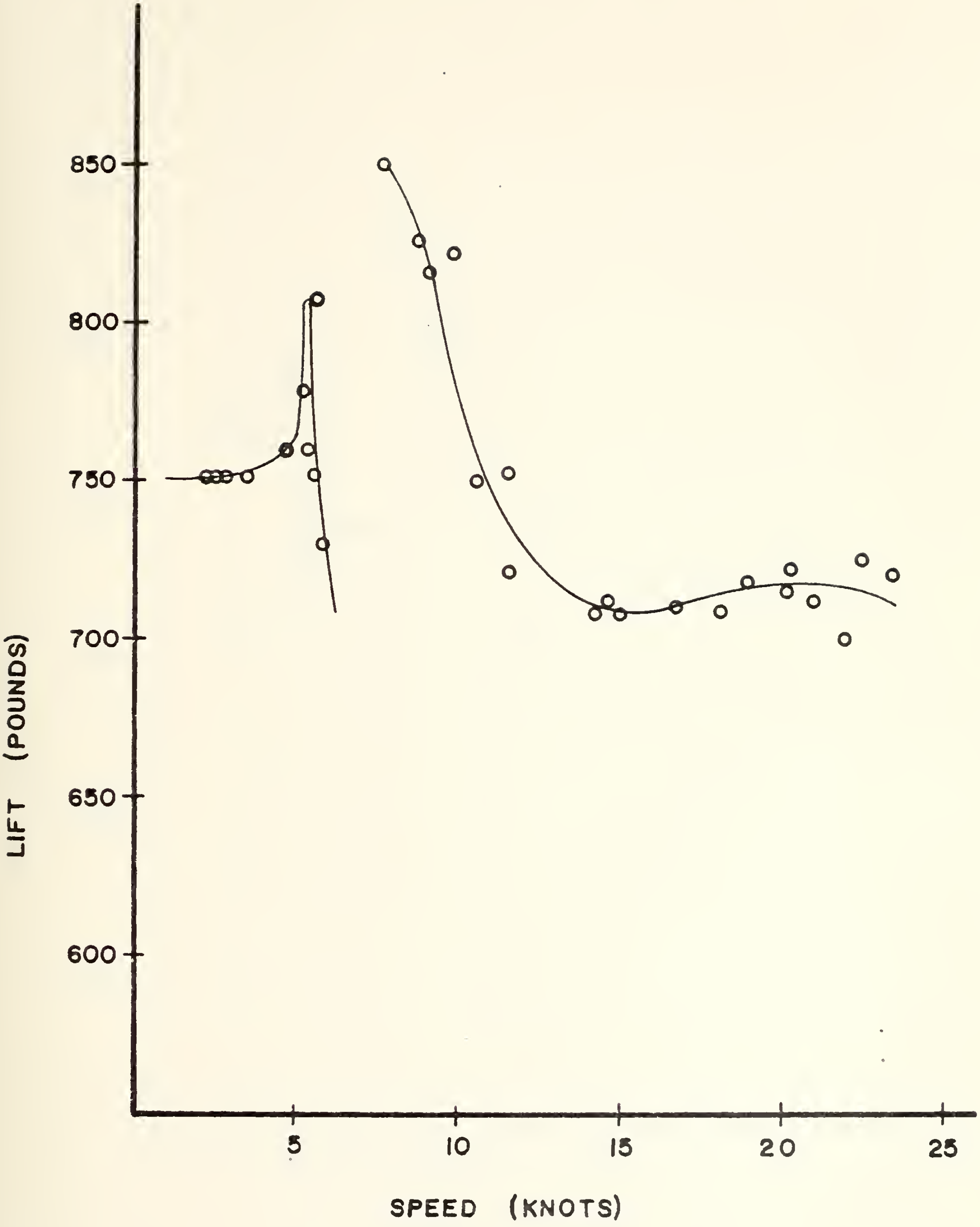

Figure 33 - LIFT VS. SPEED - CONDITION 1

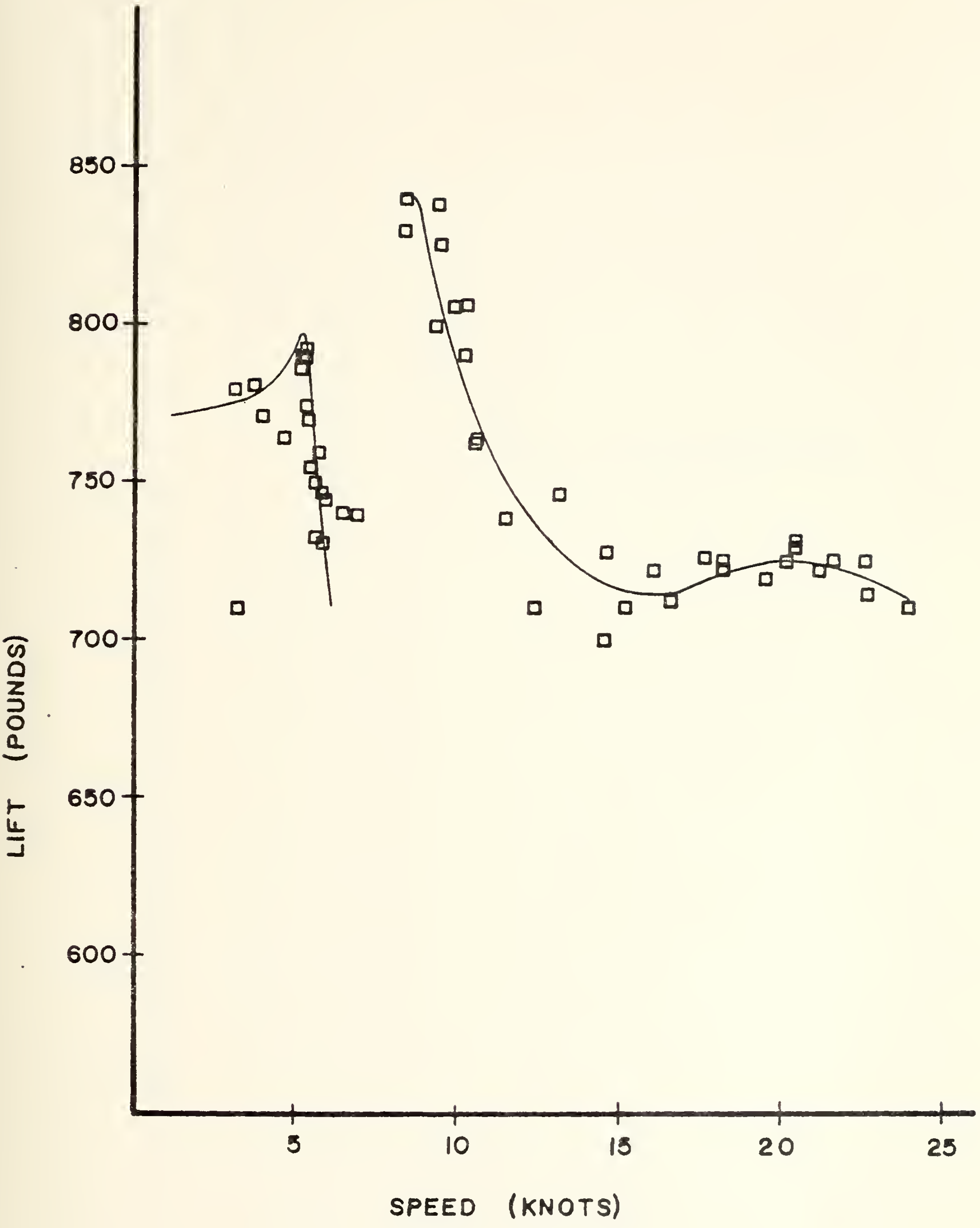

Figure 34 - LIFT VS. SPEED - CONDITION 2

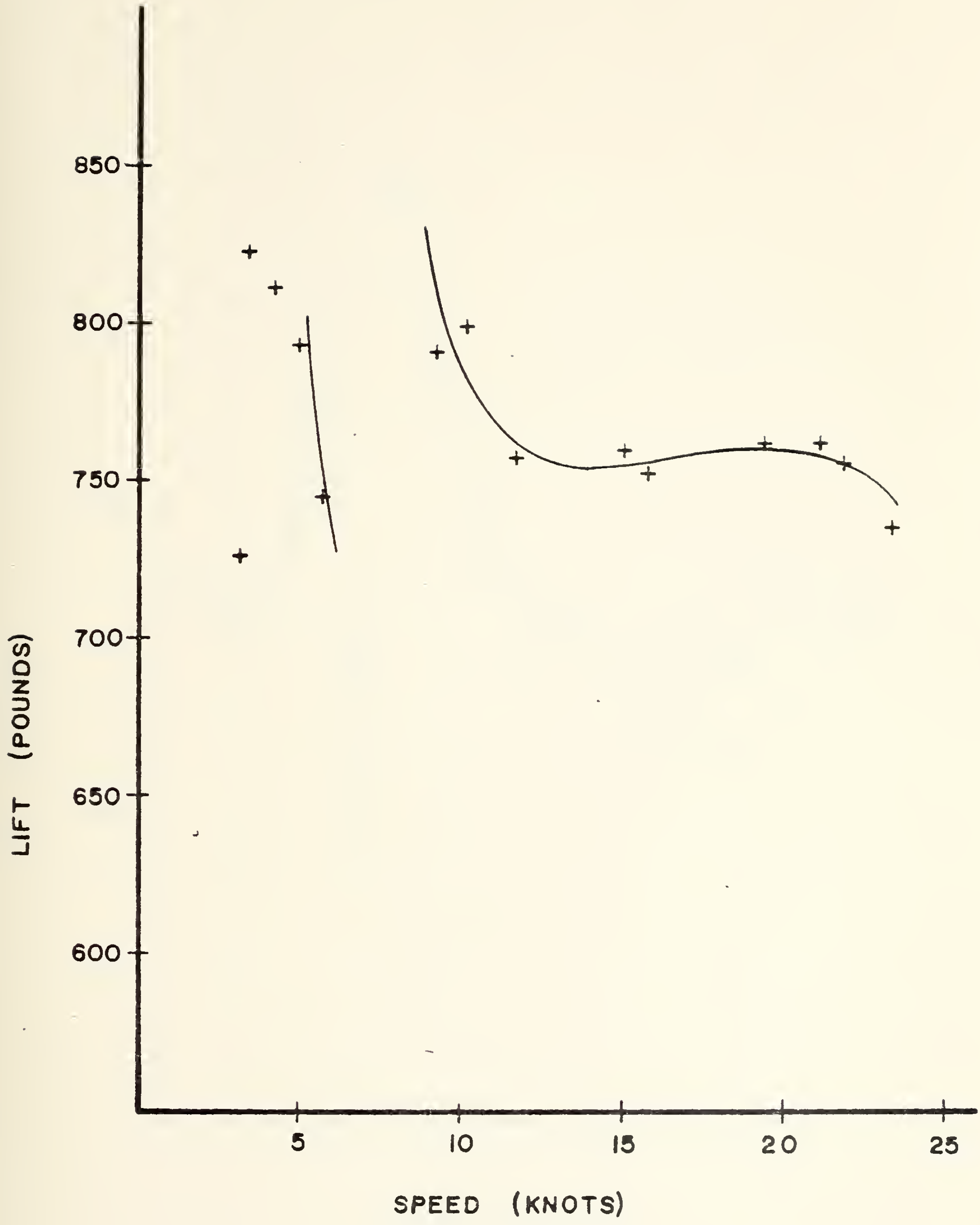

Figure 35 - LIFT VS. SPEED - CONDITION 3

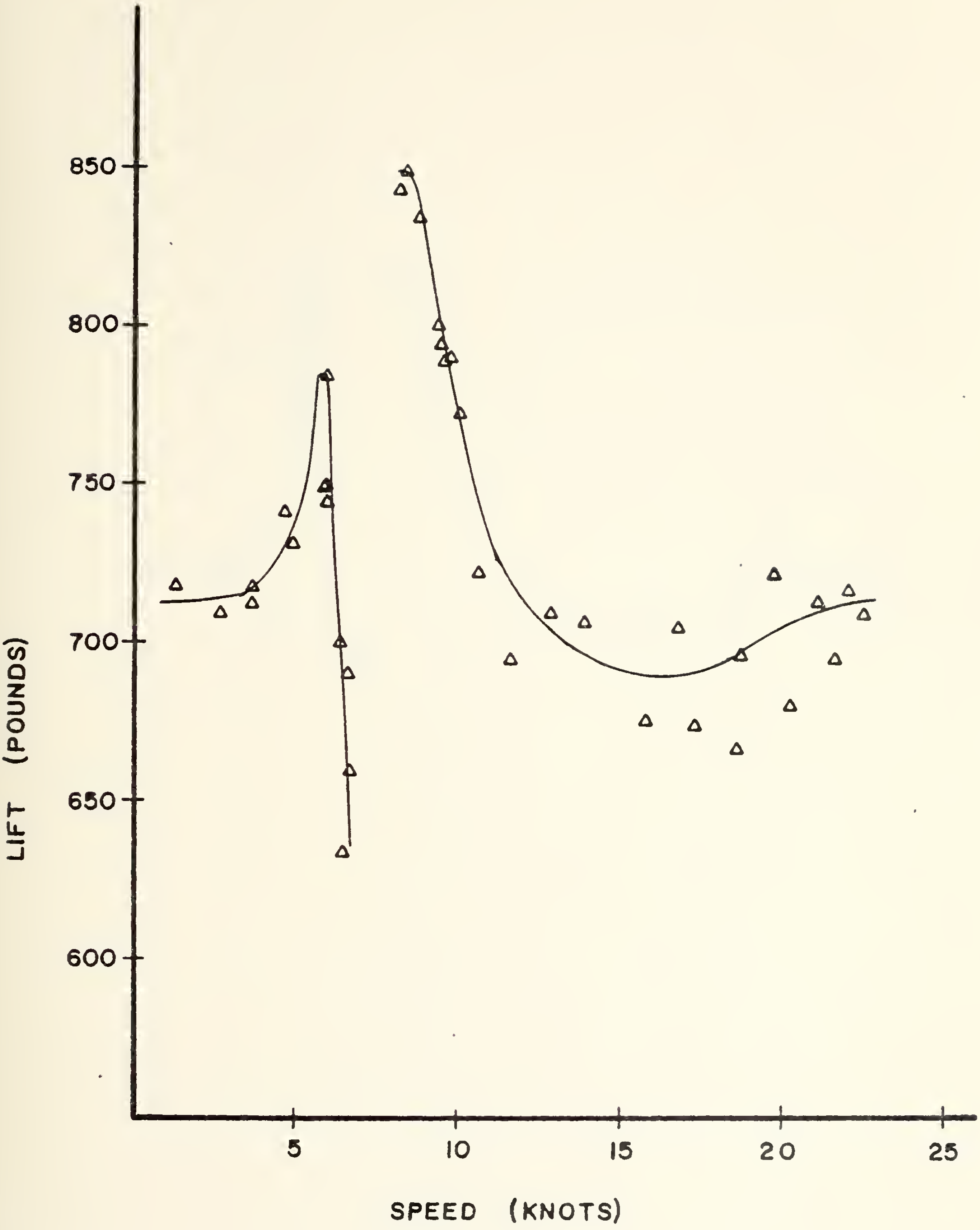

Figure 36 - LIFT VS. SPEED - CONDITION 4

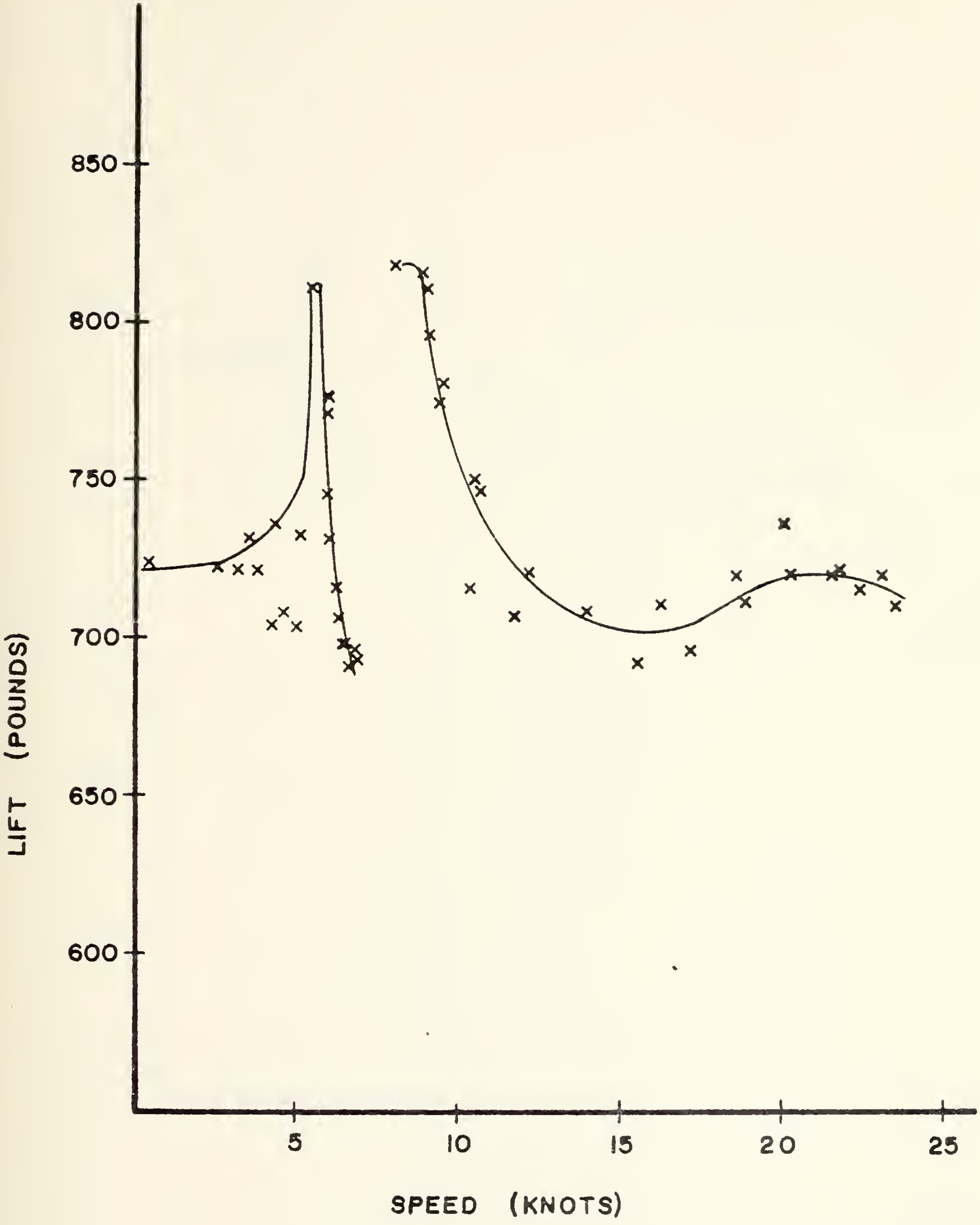

Figure 37 - LIFT VS. SPEED - CONDITION 5

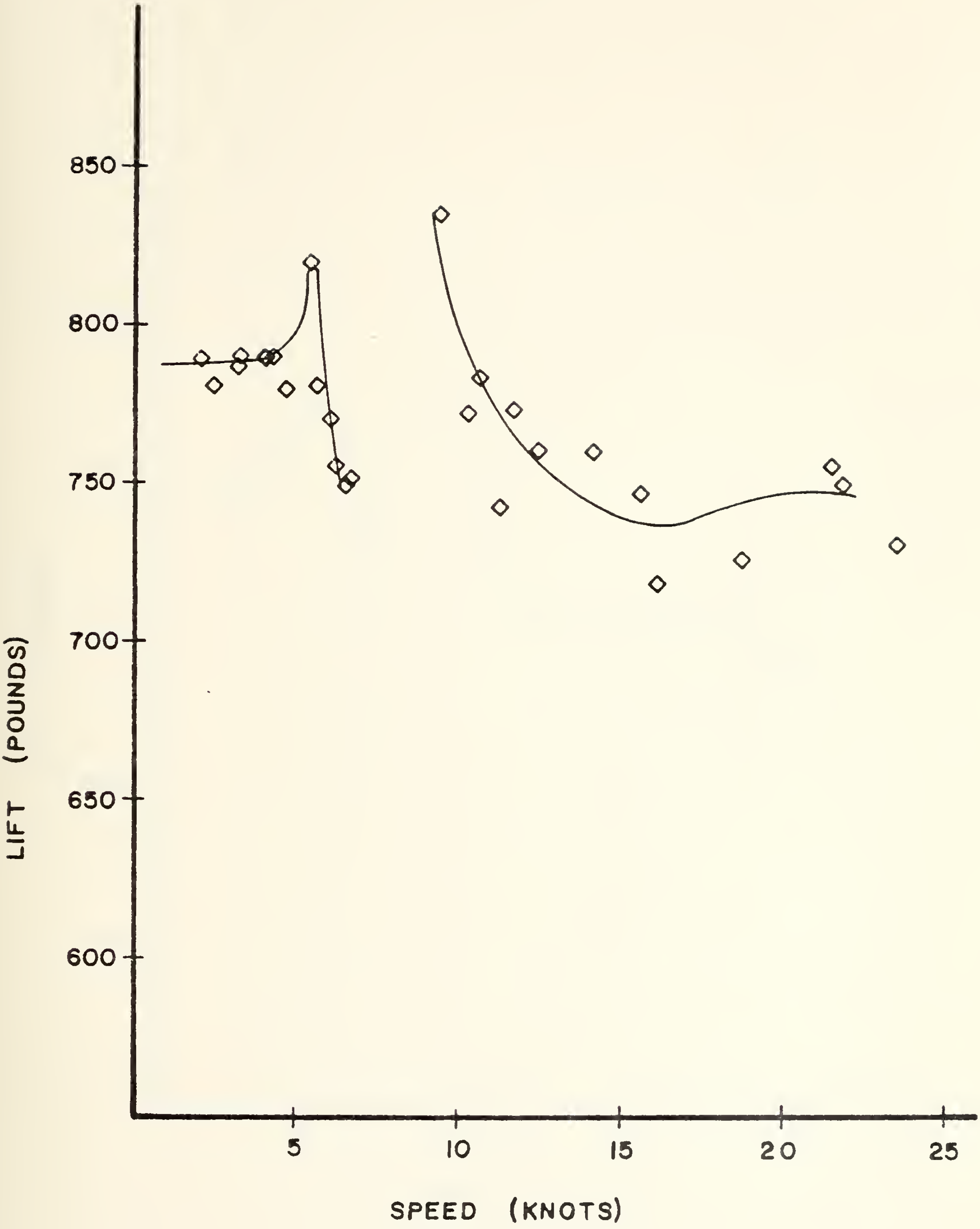

Figure 38 - LIFT VS. SPEED - CONDITION 6

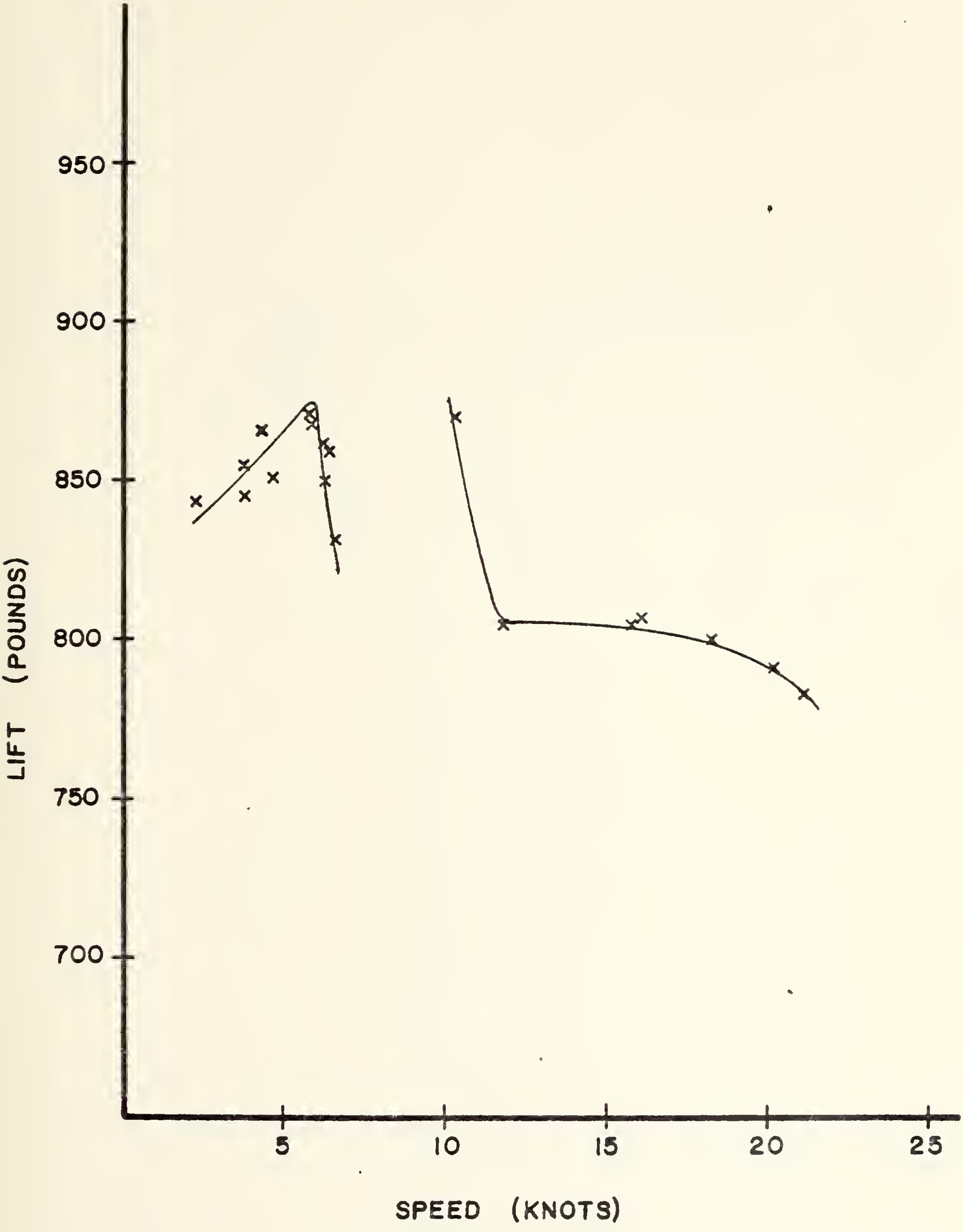

Figure 39 - LIFT VS. SPEED - CONDITION 7

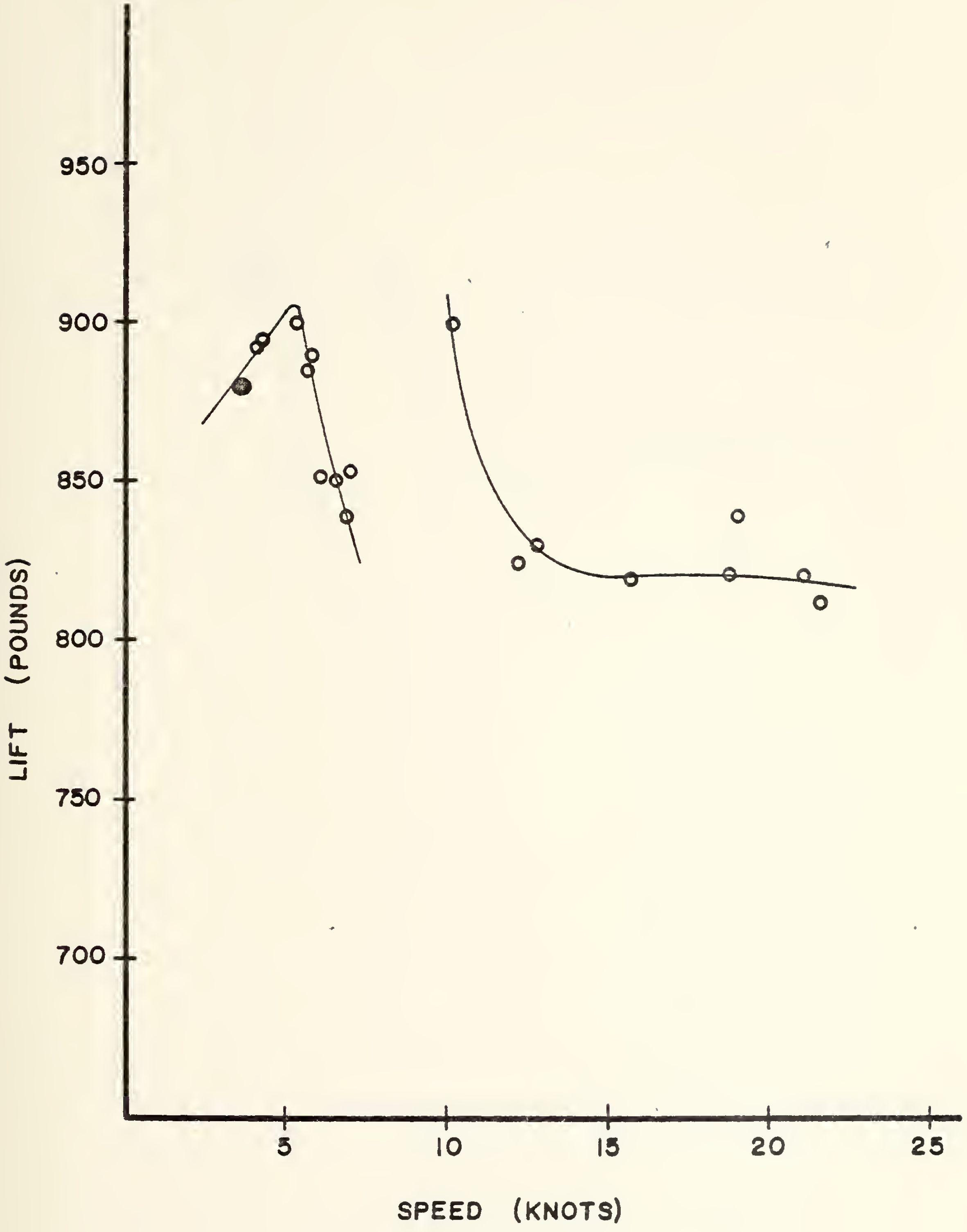

Figure 40 - LIFT VS. SPEED - CONDITION 8

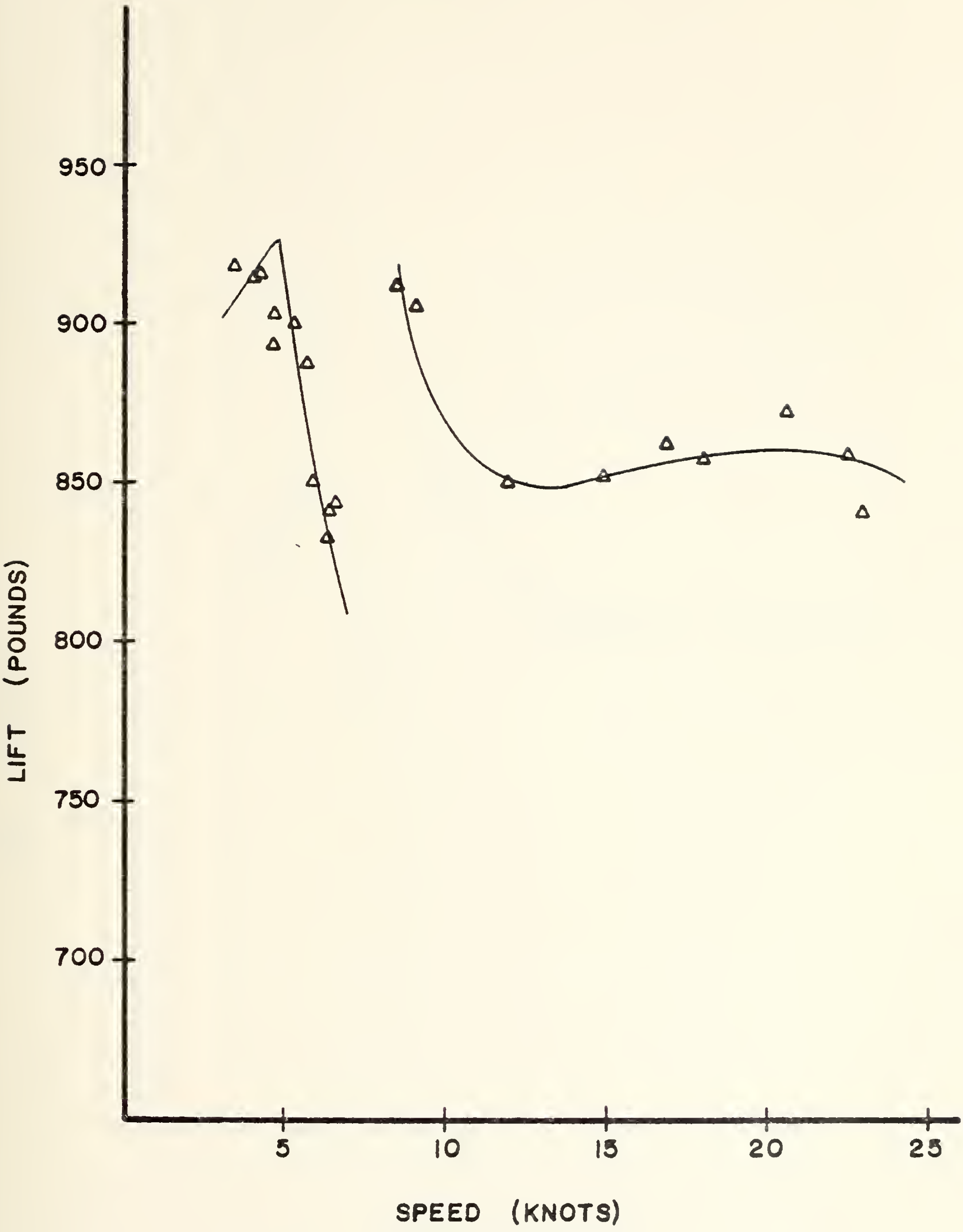

Figure 41 - LIFT VS. SPEED - CONDITION 9

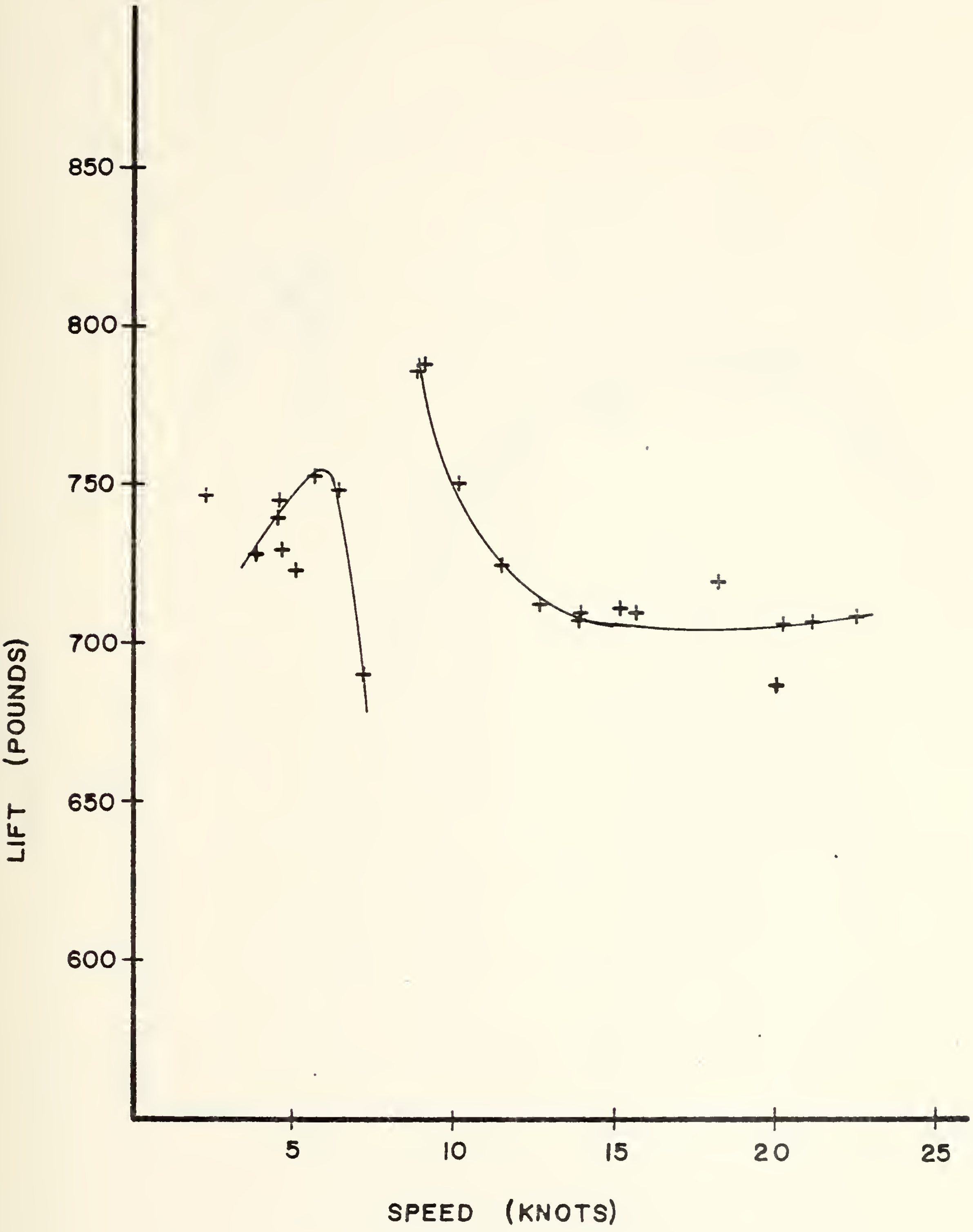

Figure 42 - LIFT VS. SPEED - CONDITION 10

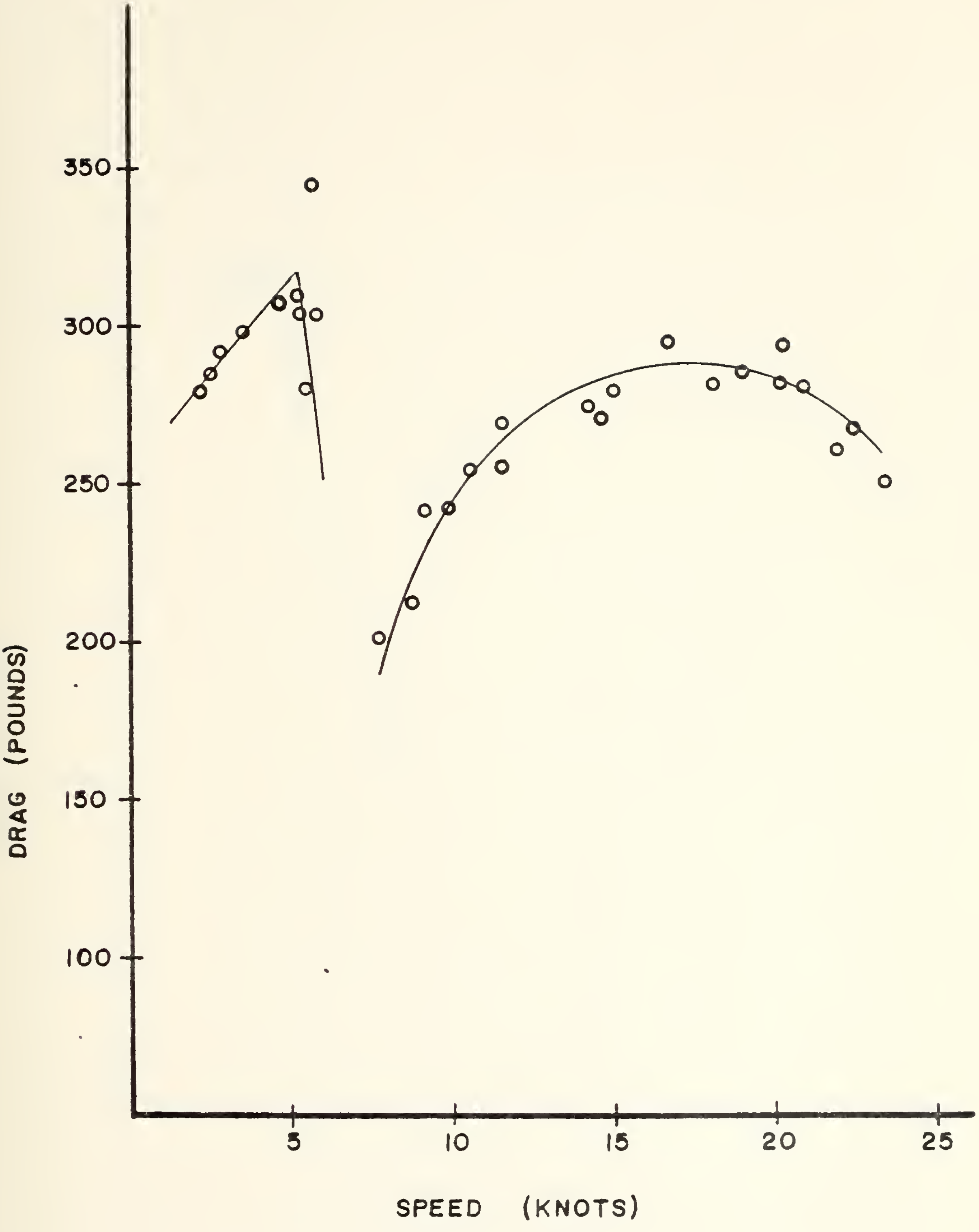

Figure 43 - DRAG VS. SPEED - CONDITION 1

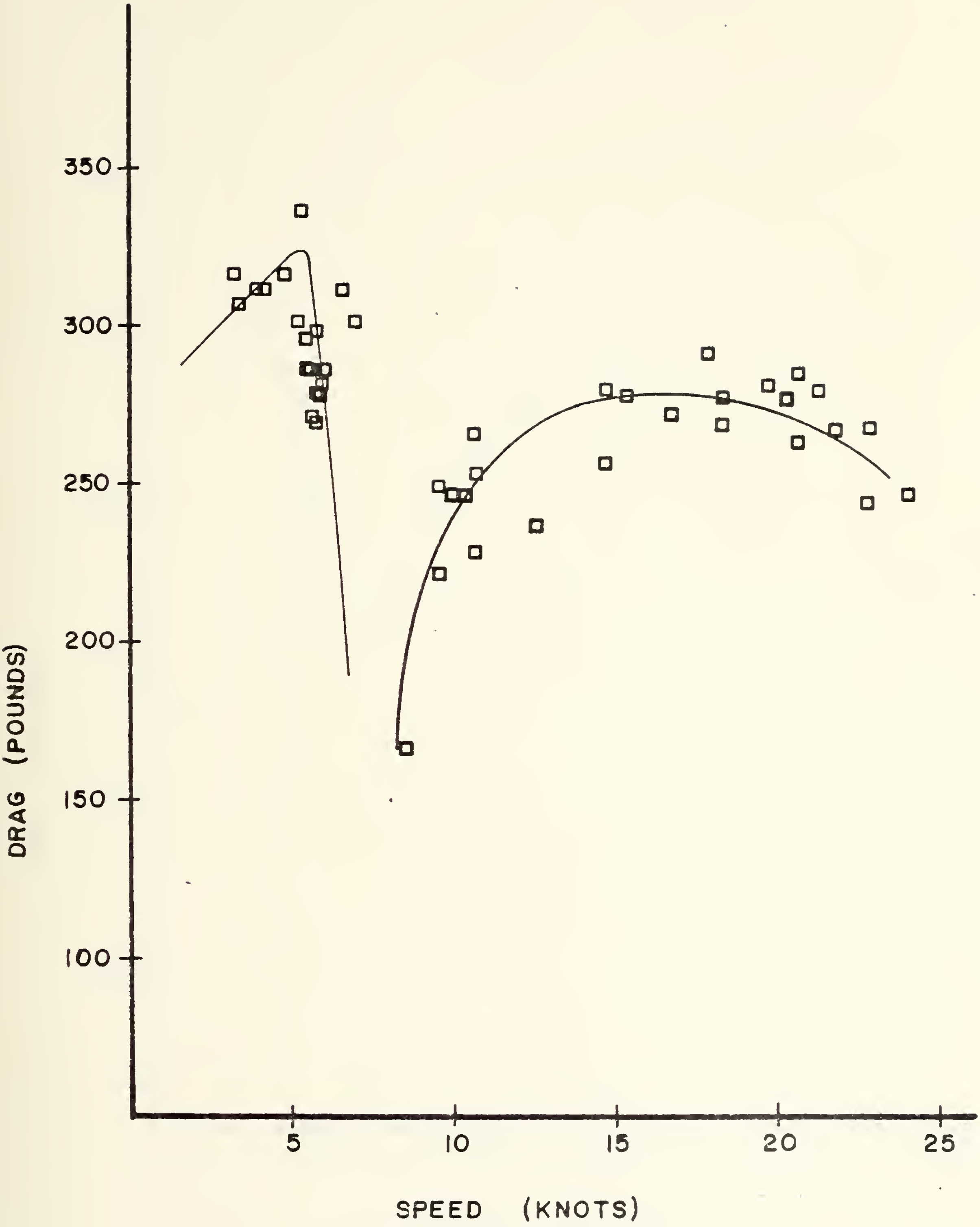

Figure 44 - DRAG VS. SPEED - CONDITION 2

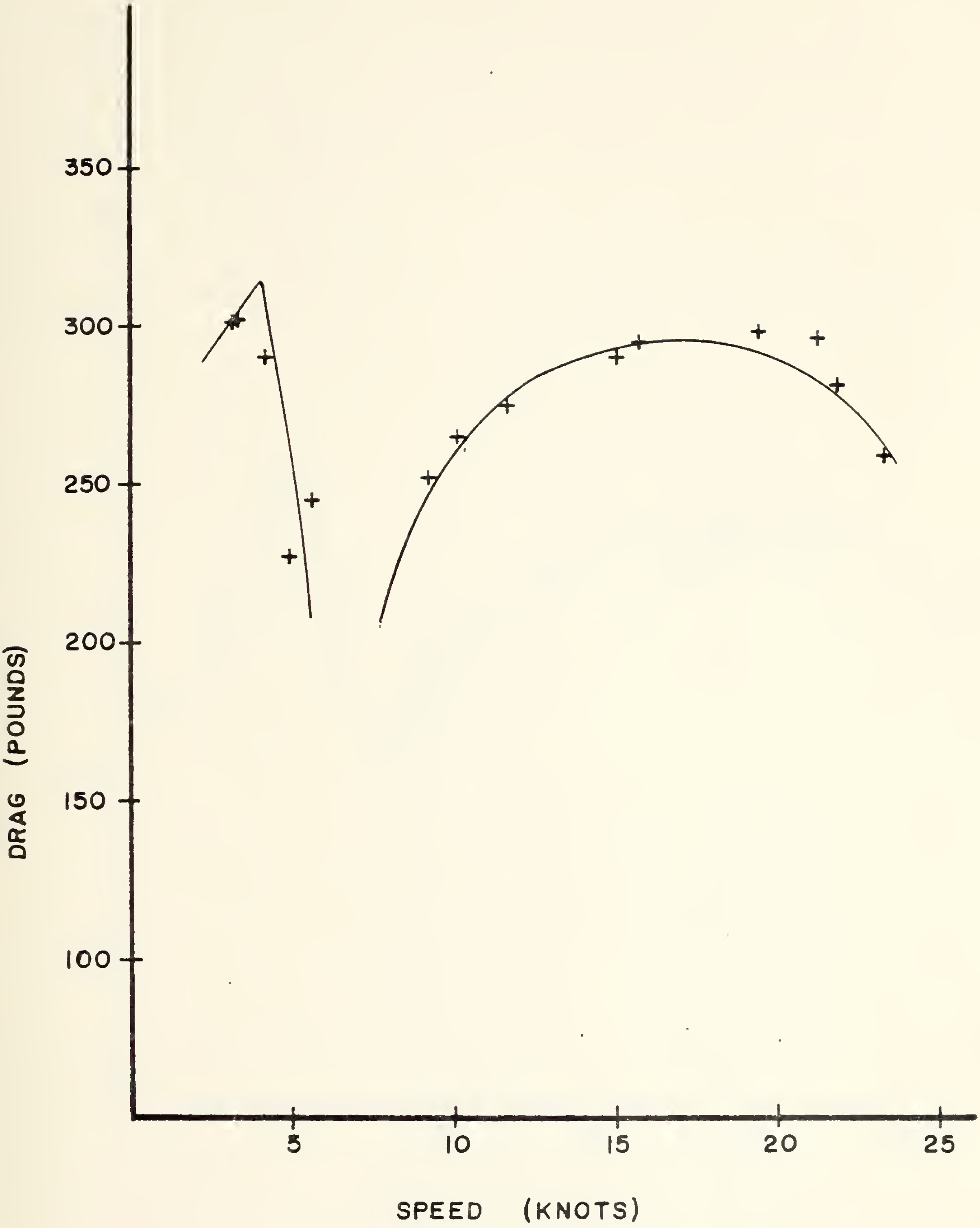

Figure 45 - DRAG VS. SPEED - CONDITION 3

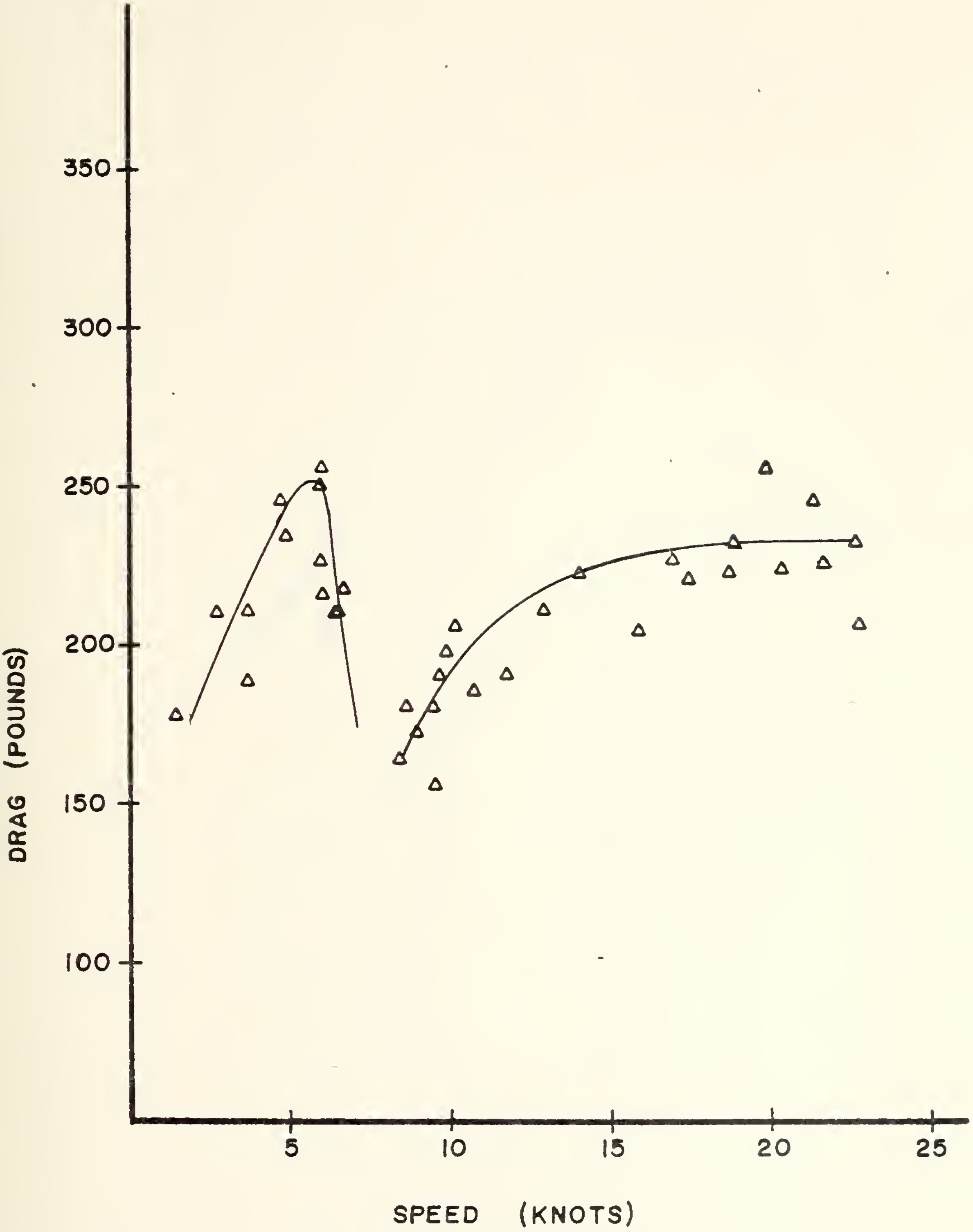

Figure 46 - DRAG VS. SPEED - CONDITION 4

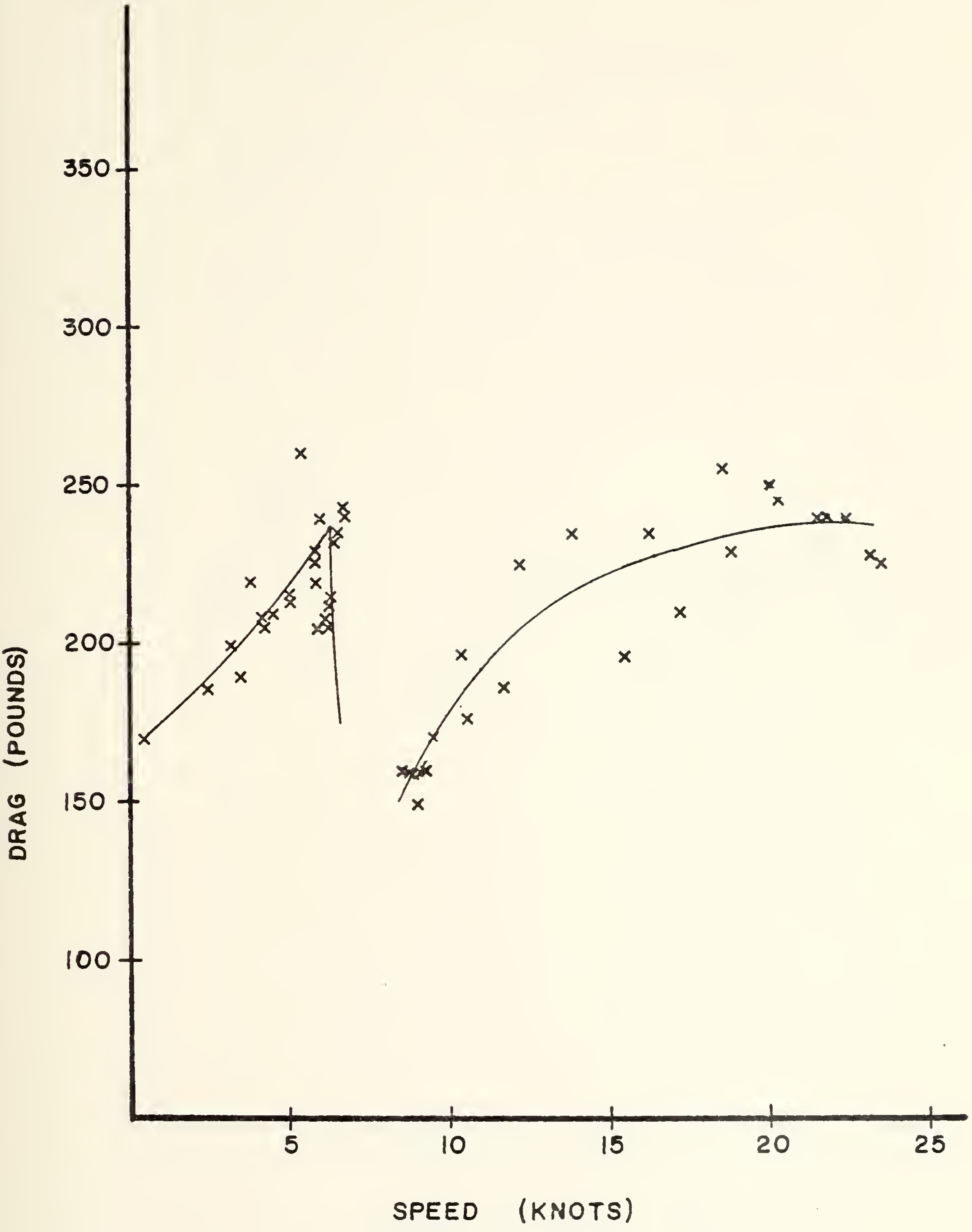

Figure 47 - DRAG VS. SPEED - CONDITION 5

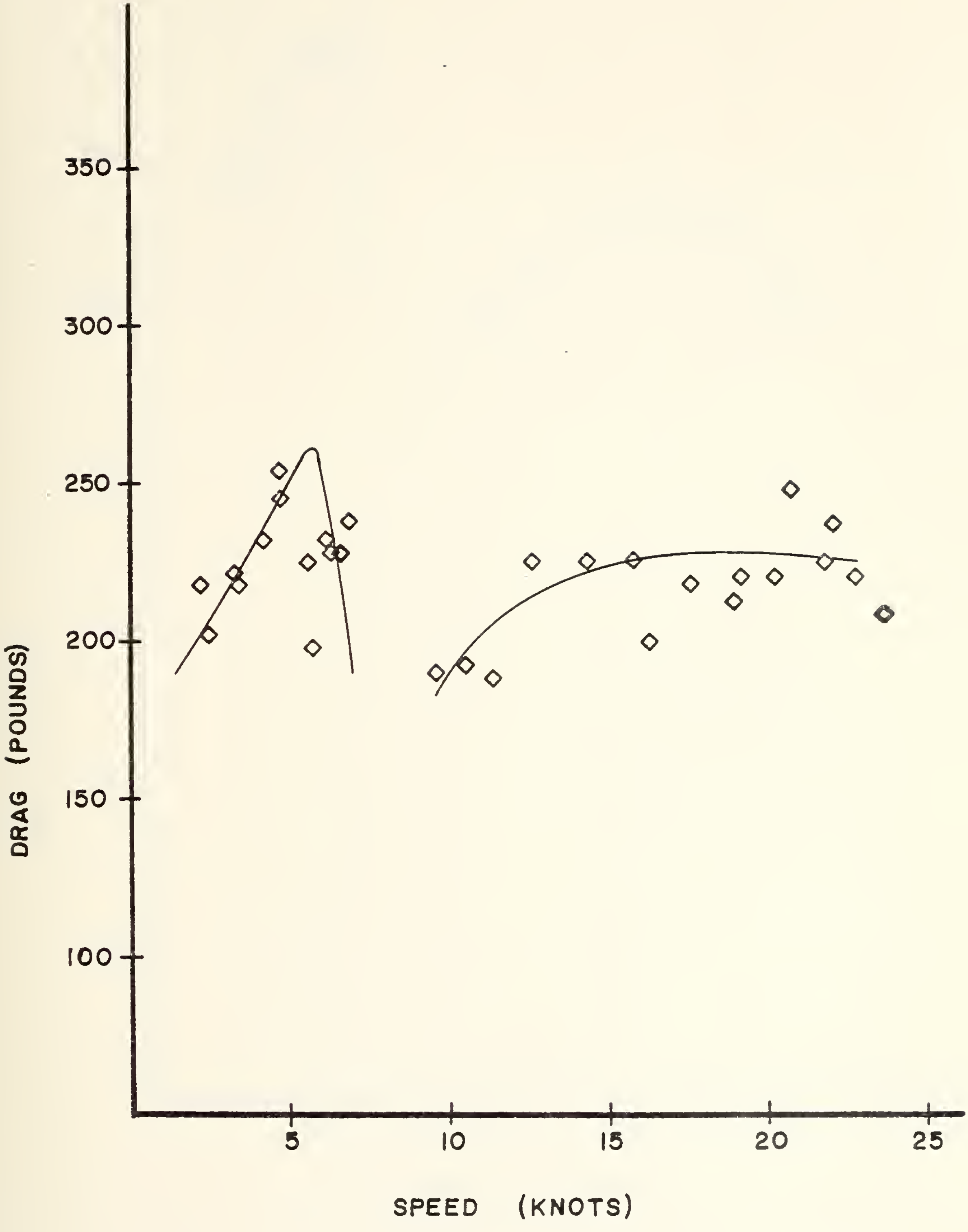

Figure 48 - DRAG VS. SPEED - CONDITION 6

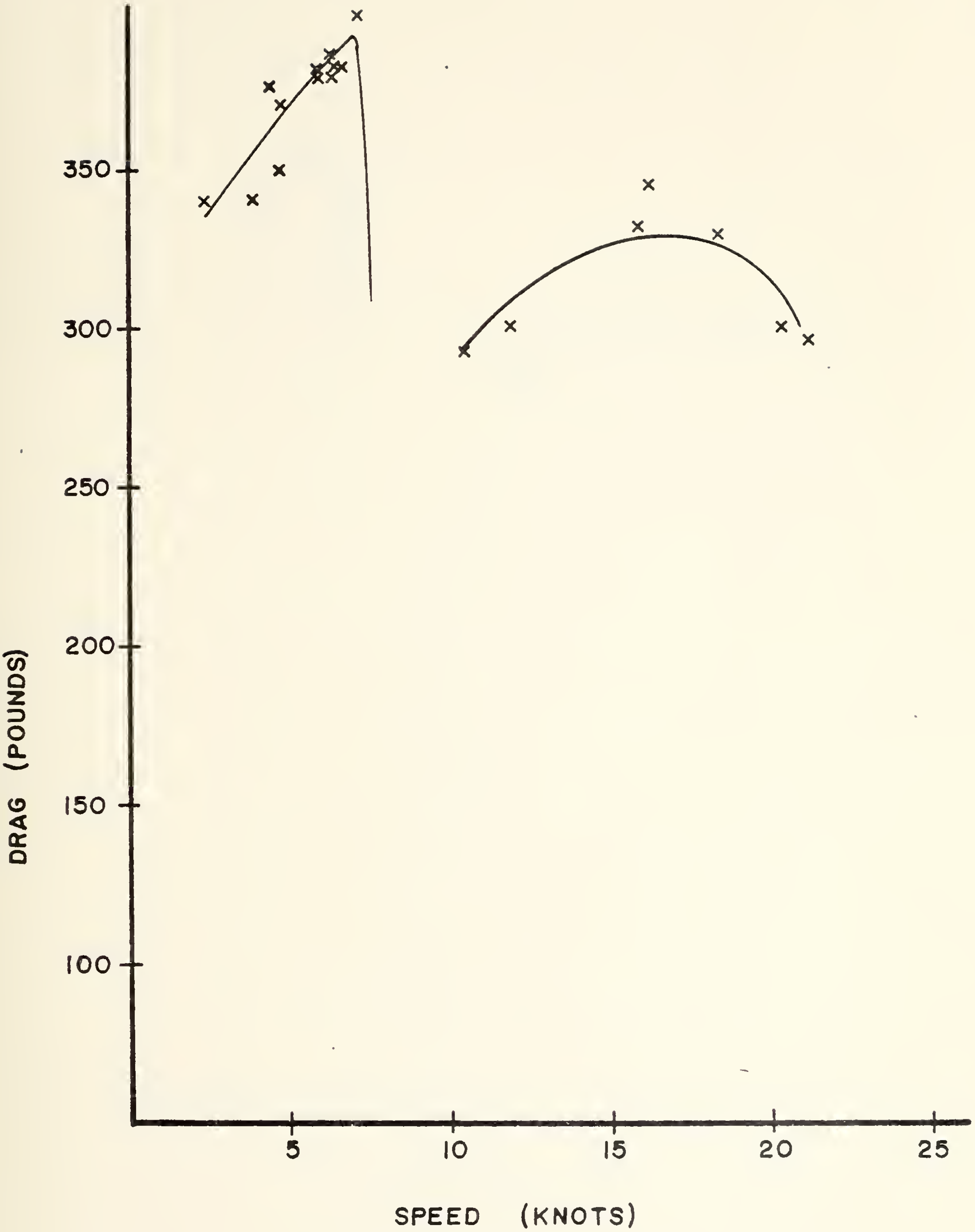

Figure 49 - DRAG VS. SPEED - CONDITION 7

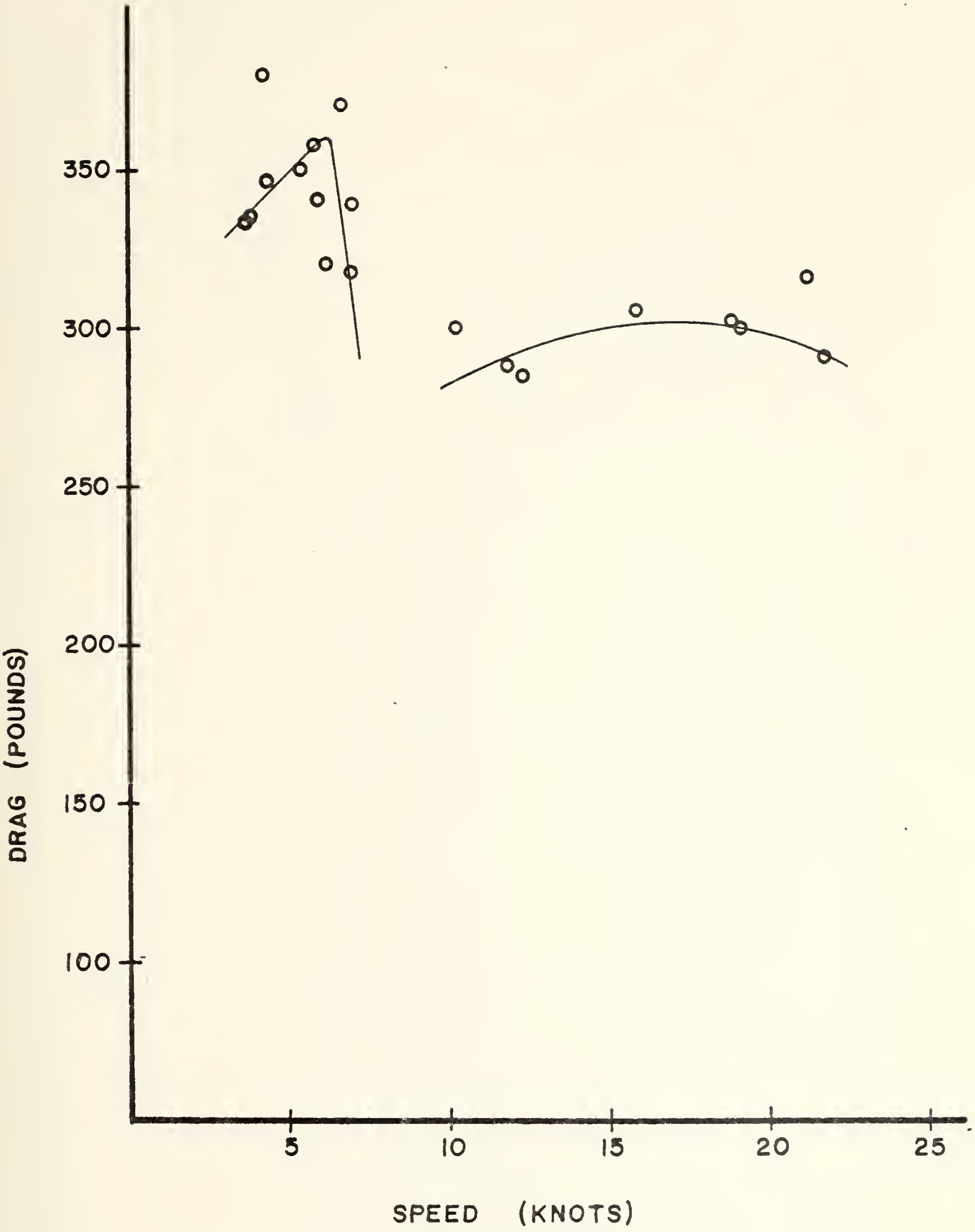

Figure 50 - DRAG VS. SPEED - CONDITION 8

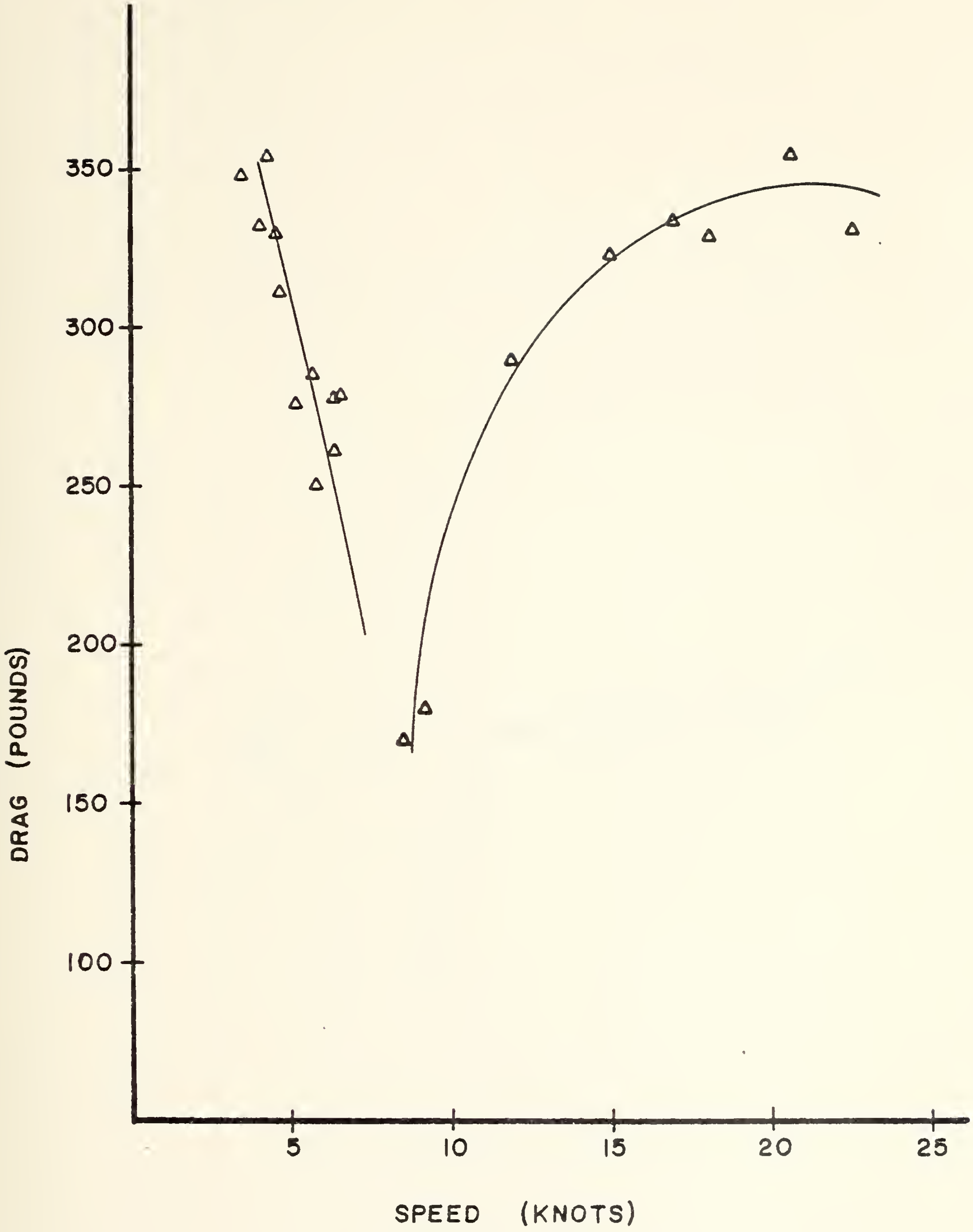

Figure 51 - DRAG VS. SPEED - CONDITION 9

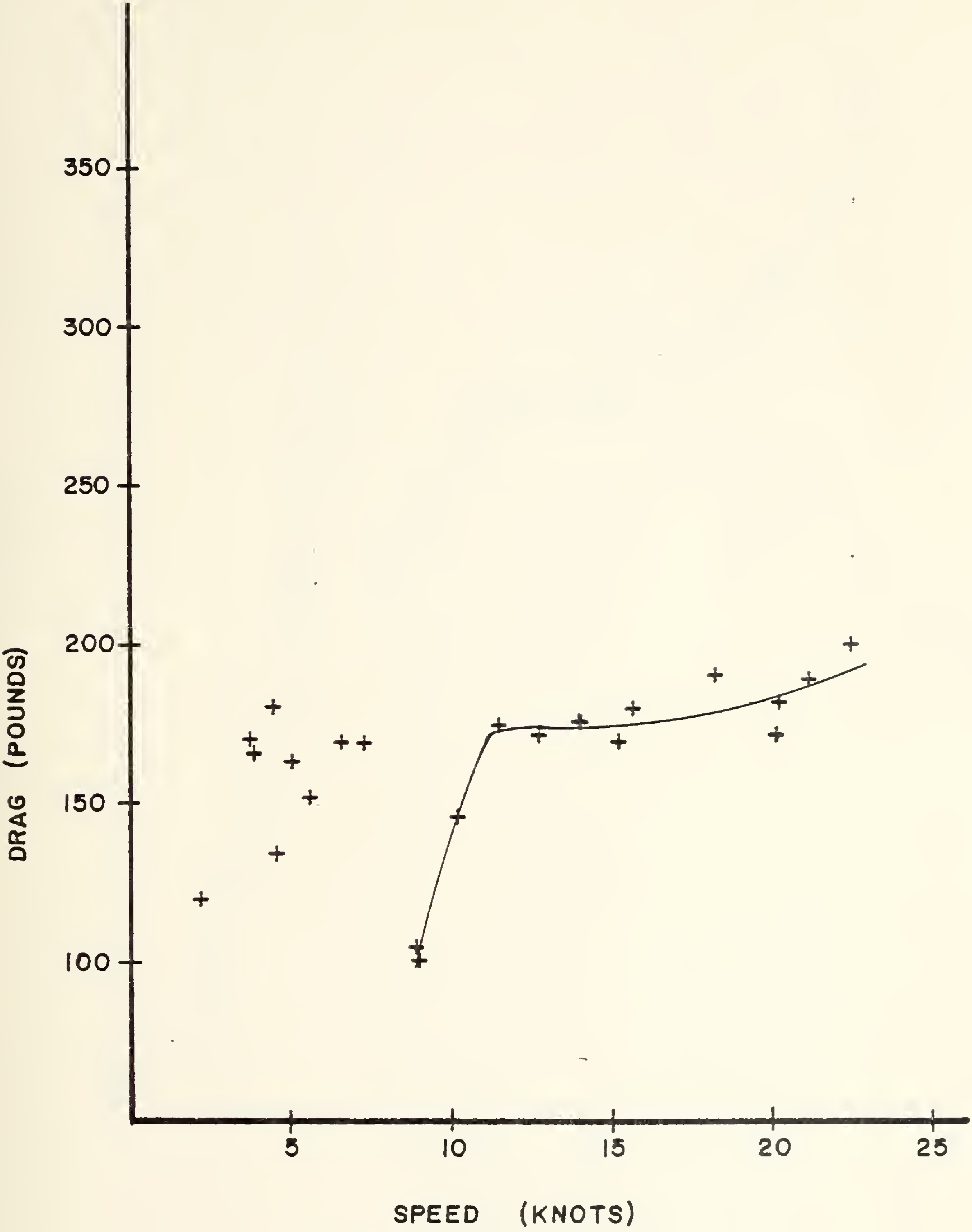

Figure 52 - DRAG VS. SPEED - CONDITION 10

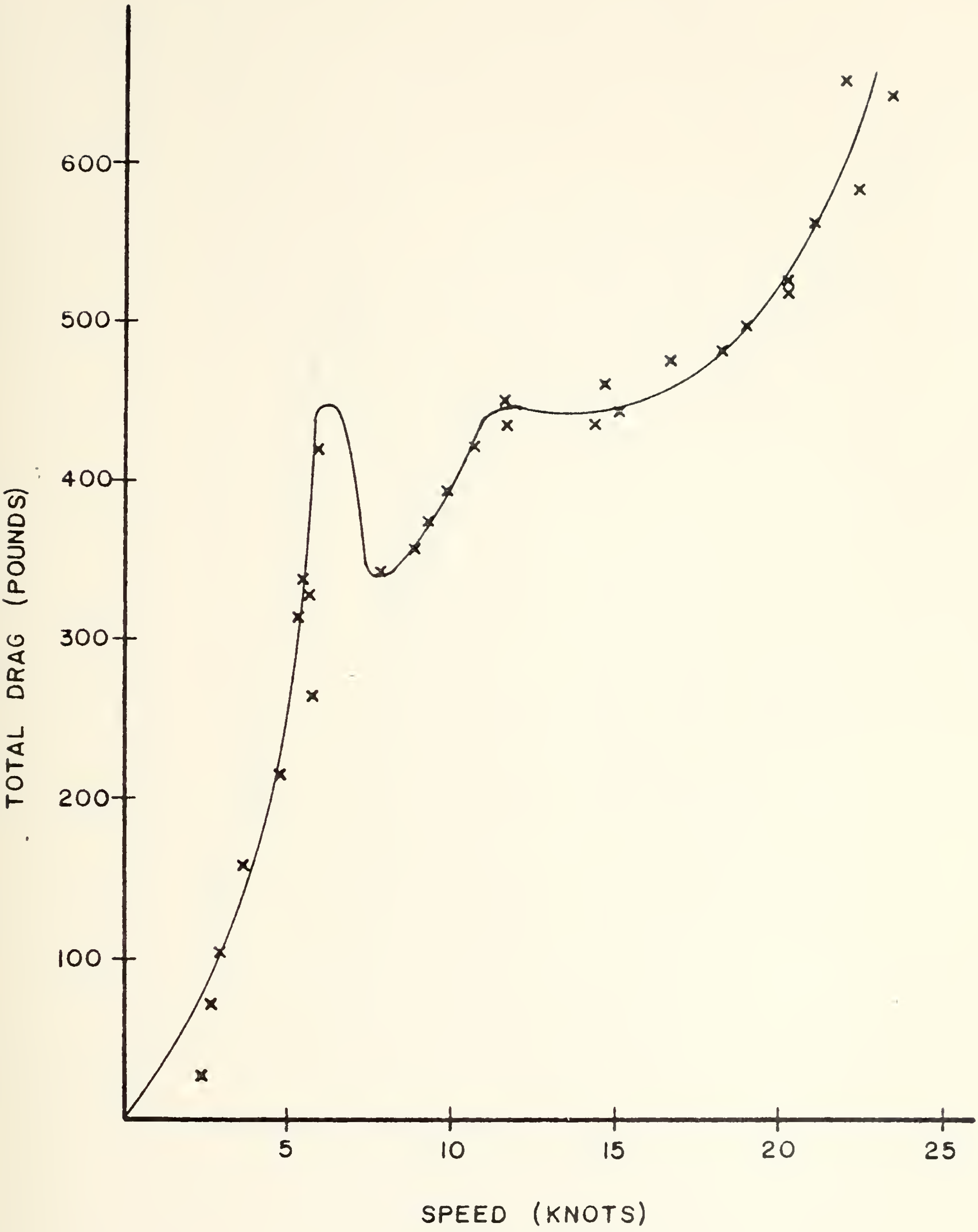

Figure 53 - TOTAL DRAG VS. SPEED - CONDITION 1

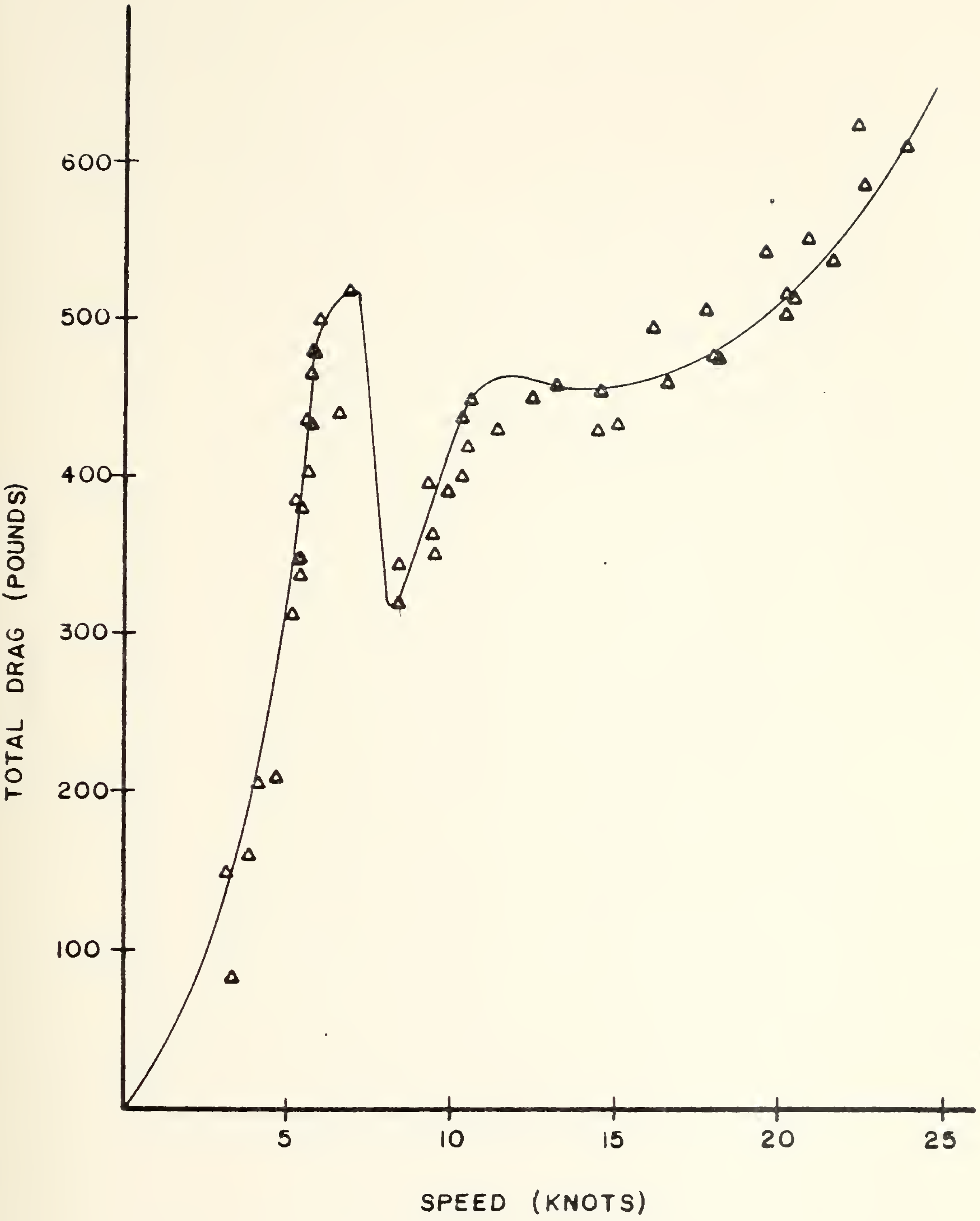

Figure 54 - TOTAL DRAG VS. SPEED - CONDITION 2

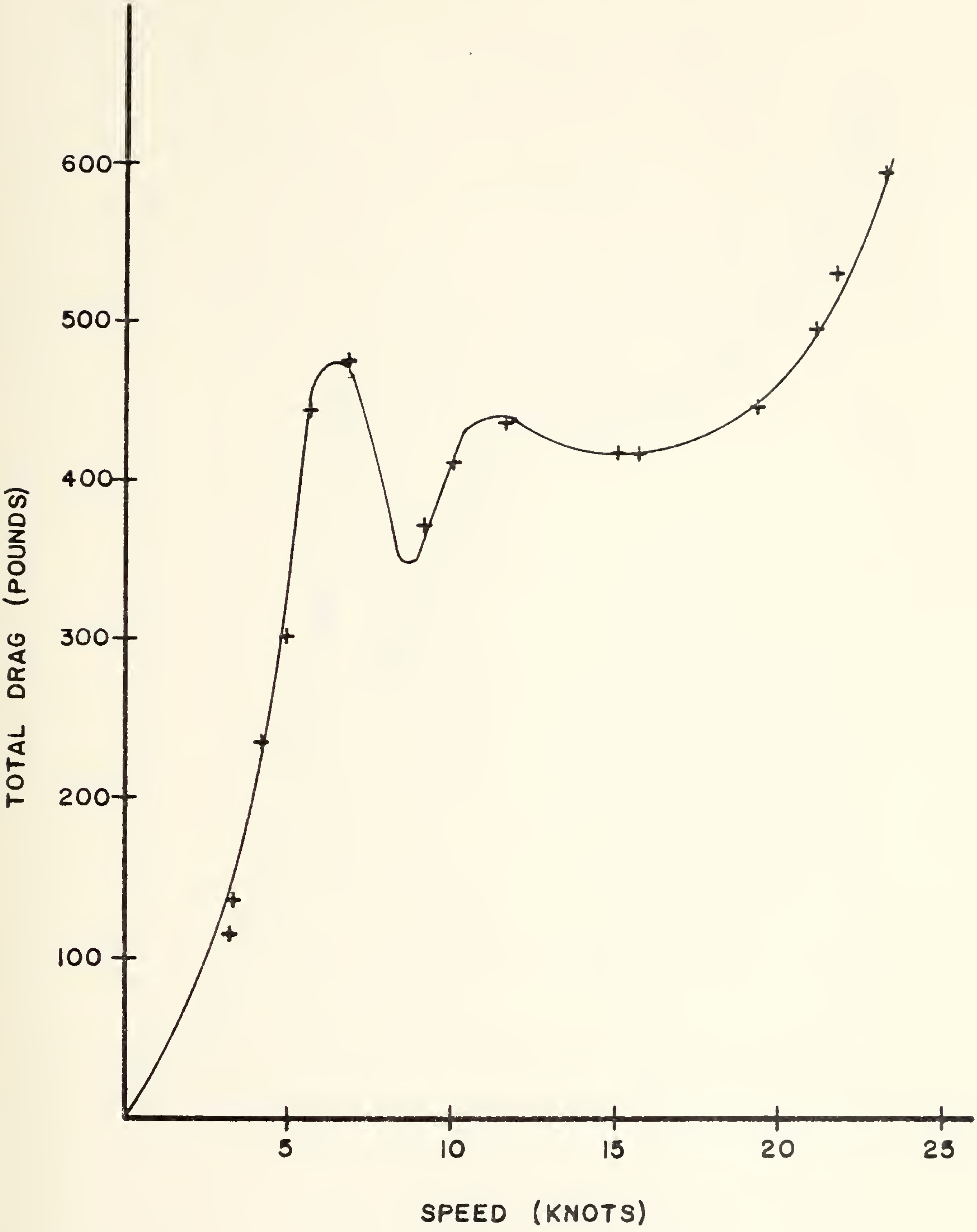

Figure 55 - TOTAL DRAG VS. SPEED - CONDITION 3

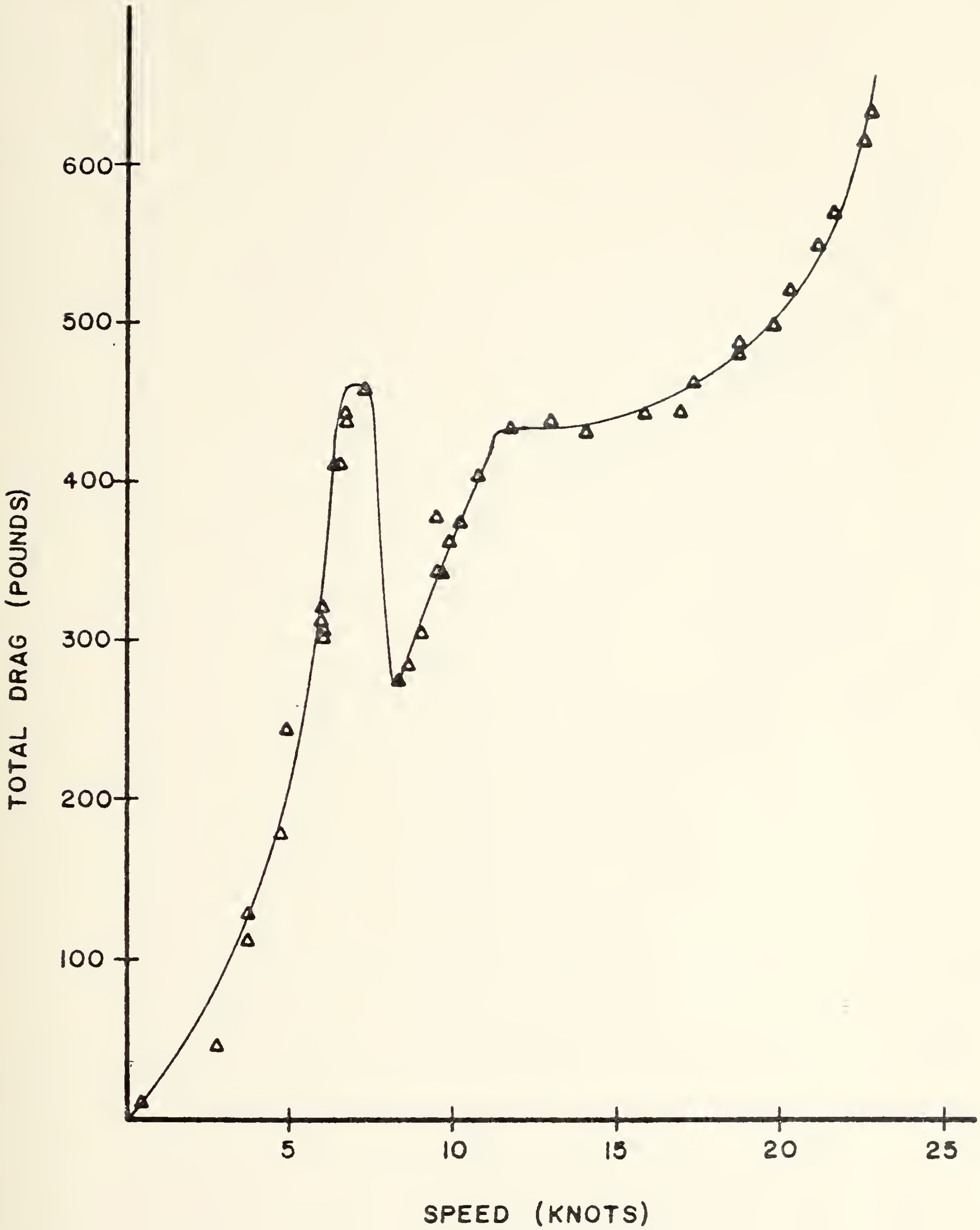

Figure 56 - TOTAL DRAG VS. SPEED - CONDITION 4

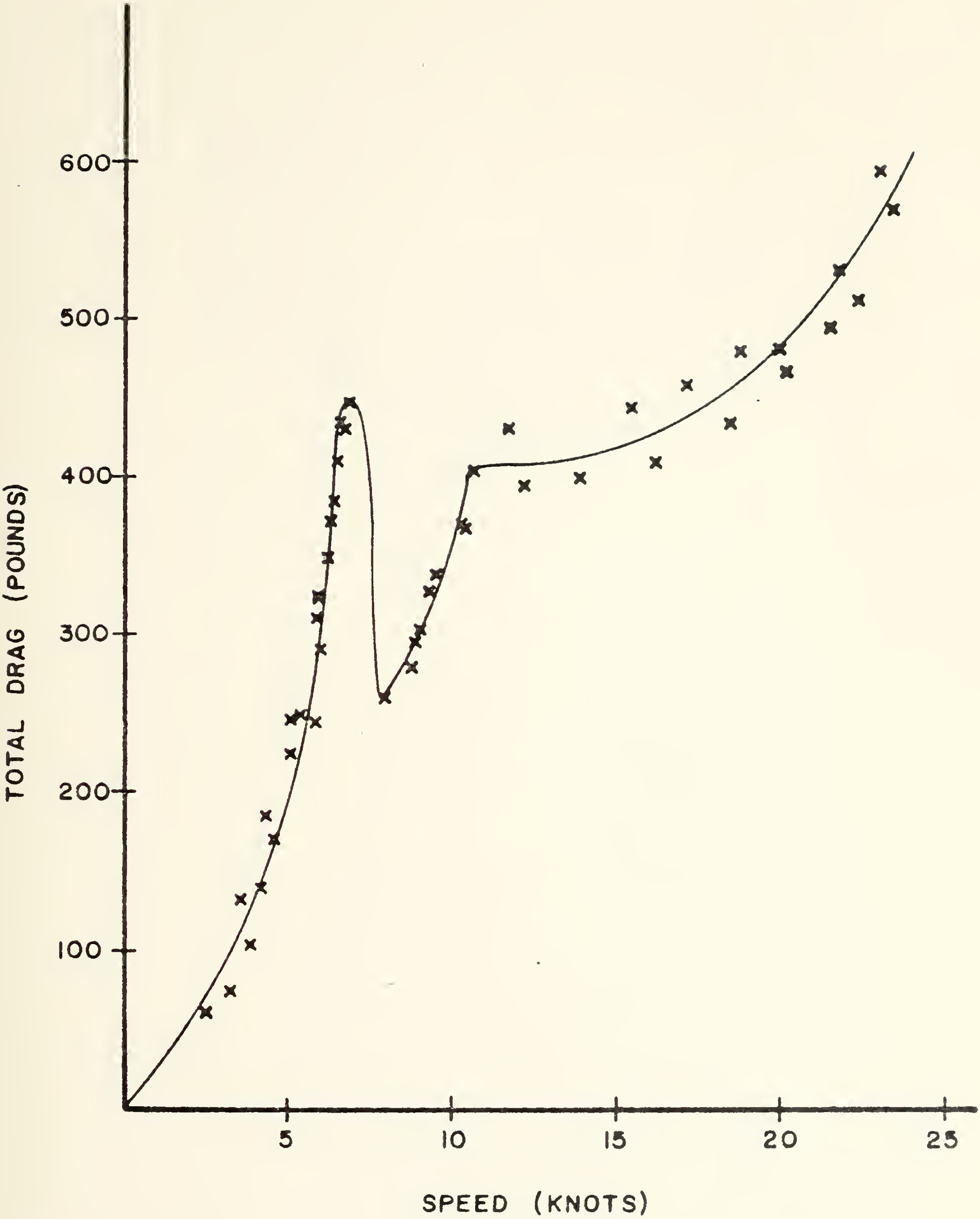

Figure 57 - TOTAL DRAG VS. SPEED - CONDITION 5

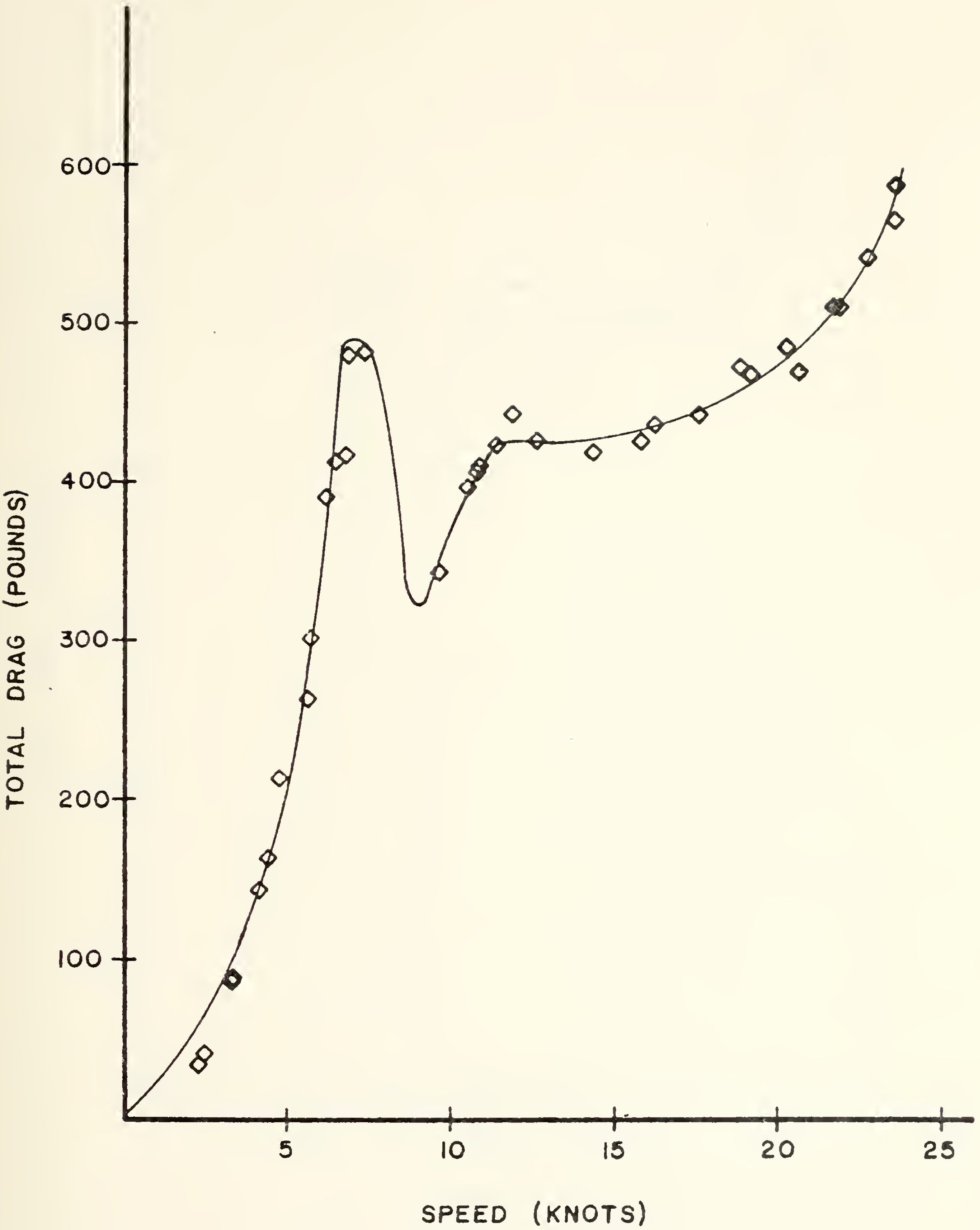

Figure 58 - TOTAL DRAG VS. SPEED - CONDITION 6

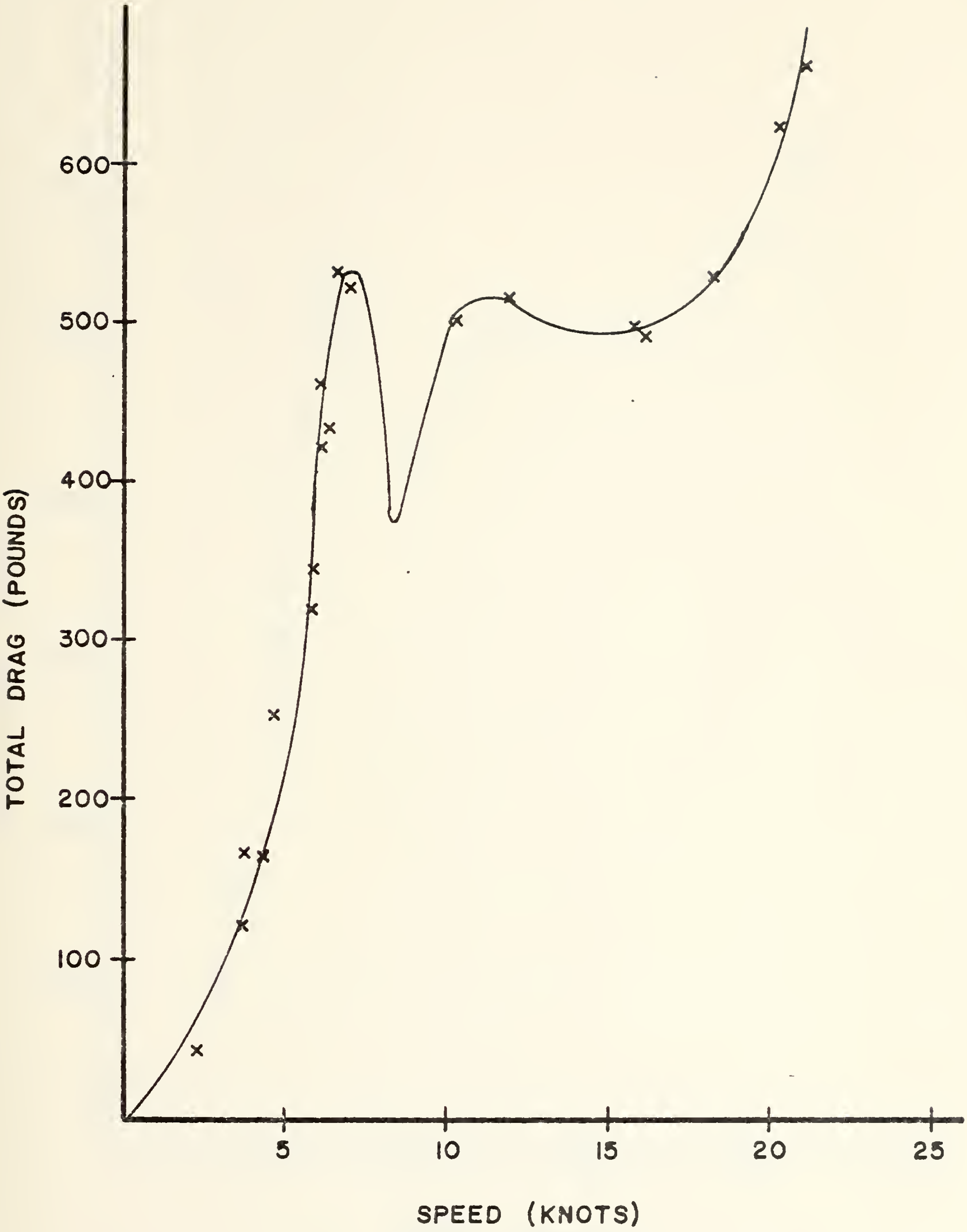

Figure 59 - TOTAL DRAG VS. SPEED - CONDITION 7

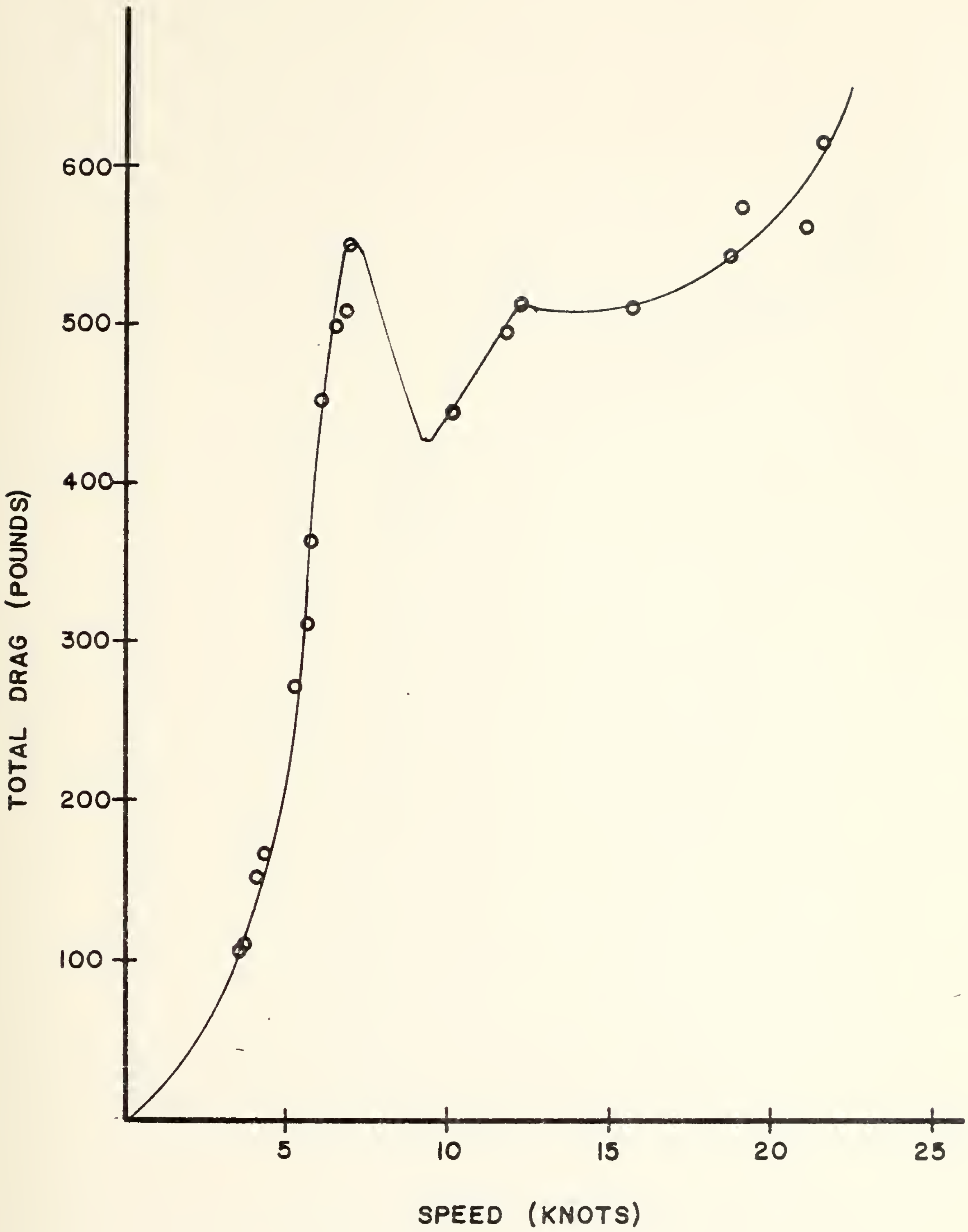

Figure 60 - TOTAL DRAG VS. SPEED - CONDITION 8

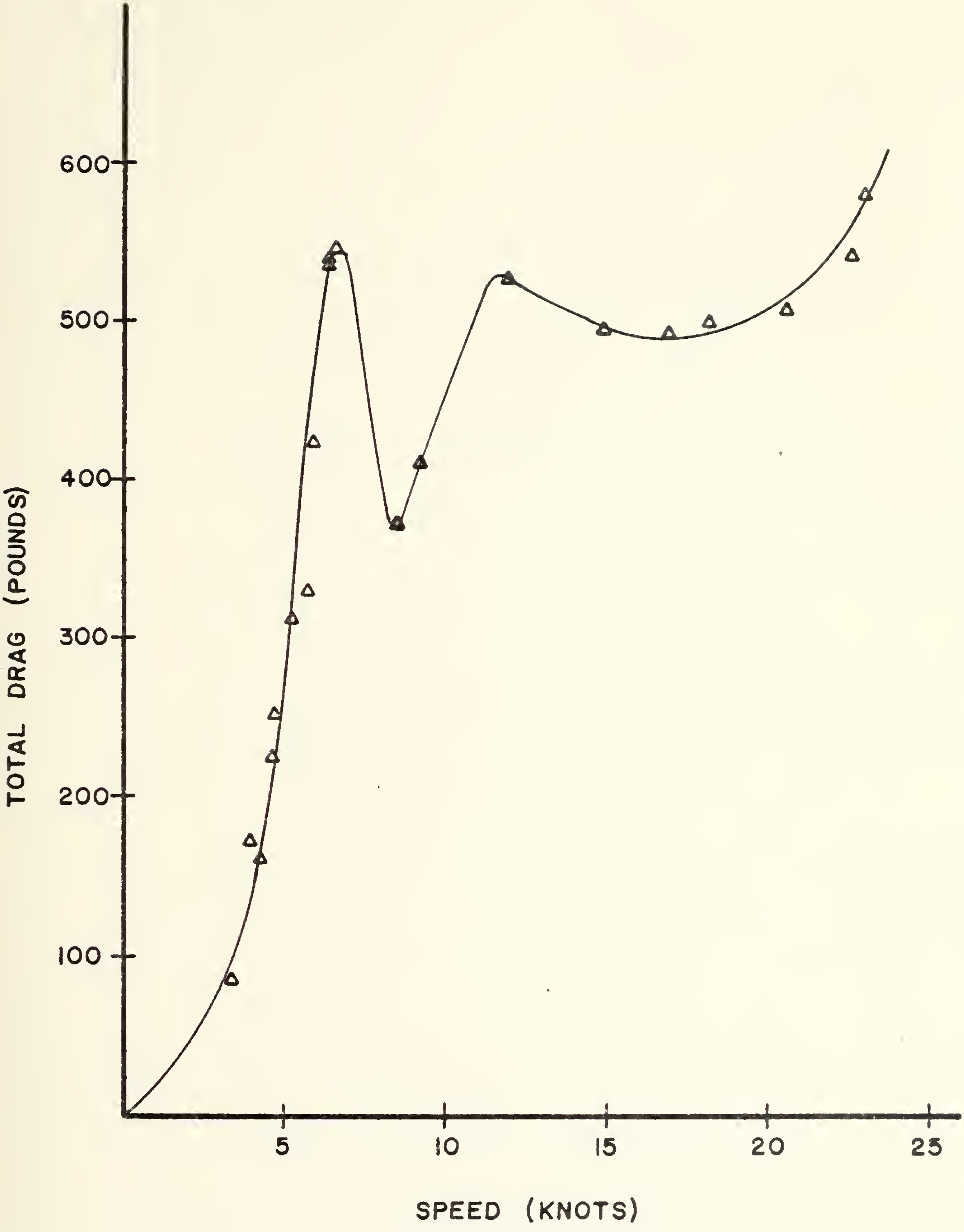

Figure 61 - TOTAL DRAG VS. SPEED - CONDITION 9

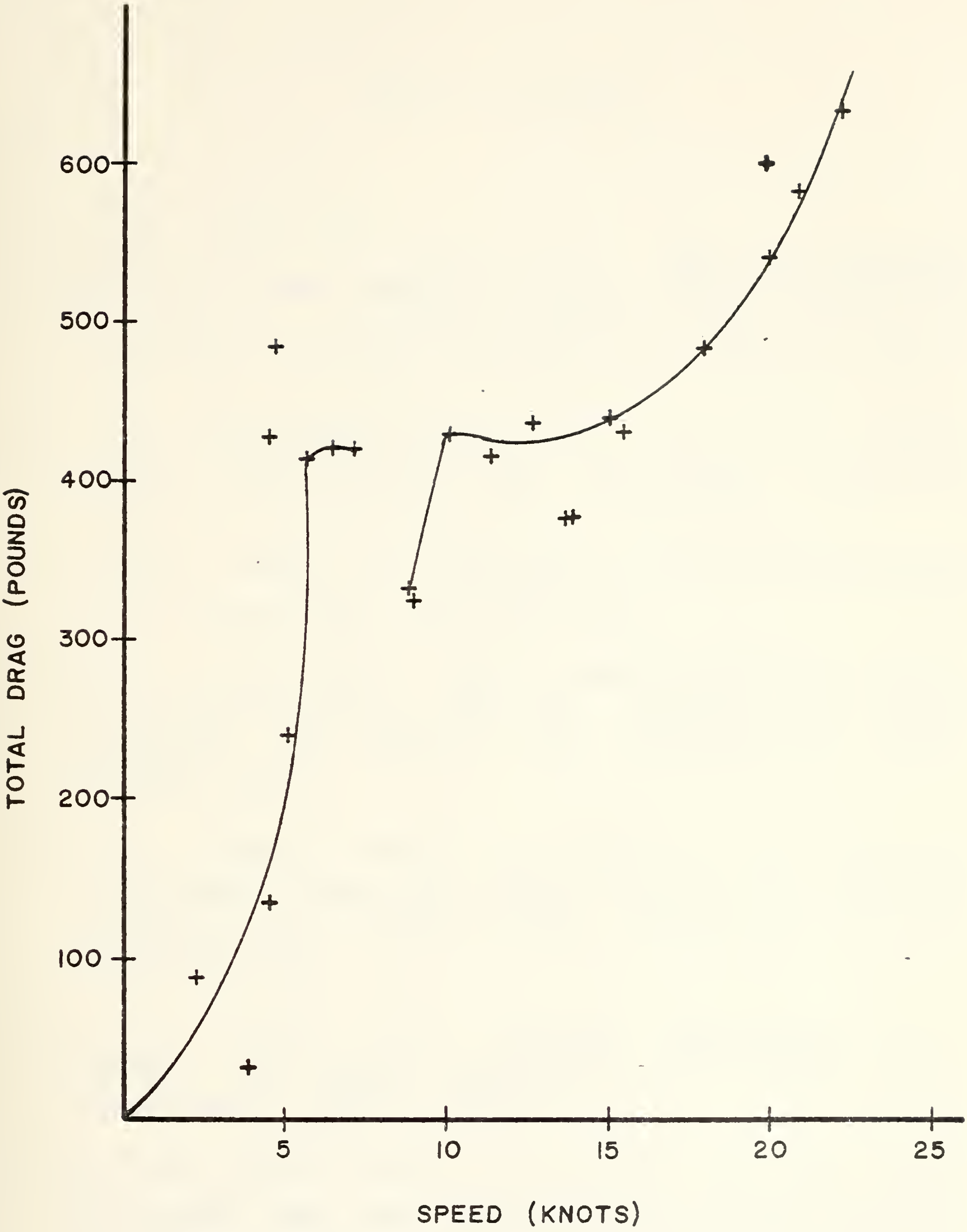

Figure 62 - TOTAL DRAG VS. SPEED - CONDITION 10

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